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134

-: HAND WRITTEN NOTES:-
OF

ELECTRICAL ENGINEERING

9

-: SUBJECT:-

ELECTRICAL MATERIALS

10

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②

Material Science :-

→ S. P. Sethi

Syllabus :-

(3)

- 1) Chemical bonding & structure of solid.
- 2) dielectric material & its properties
- 3) Magnetic material & its properties.
- 4) Insulator — Ceramic

Semi Conductor — $\begin{cases} \text{ESM (elemental s/c material)} \\ \text{CSM (Compounded s/c material)} \end{cases}$

Conductor — Super conductor

$\text{SiC} \rightarrow \text{IV Compound semiconductor}$
↓ ↓
Valency Valency
4 4

(4)

** Chemical bonding & structure of Solid →

Chemical bonding → The binding forces b/w atoms or molecules are known as chemical bond. There are two types of chemical bond.

- (a) Primary
- (b) Secondary

(a) Primary → (i) These bonds are inter atomic bonds
(ii) These bonds are having higher bond energy
Ex - Ionic, Covalent & metallic bond.

(b) Secondary → These bonds are inter molecular bonds.

These bonds are having lesser bond energy as compared to primary bonds.

Ex - Vander Waal's bond
Hydrogen bond.

(i) Ionic bond → The ionic bond is a bond resulting from the electrostatic interaction of oppositely charged ions by transfer of e^- from one to other.

Ionic Solid are formed particularly elements on the left & right hand side of the periodic table. Ex (Group-1 & Group-7) (6)

Group-1 elements are 'Alkalies' element (Li, Na, K, Rb, Cs, Fr).

Group-7 element are 'Halogens'. (Br, Cl, I, F)

→ The Alkali halide form b/w the alkalis metal & the halogen are strongly ionic.

General char of Solids having Ionic bond →

- ① Higher strength
- ② higher melting point
- ③ Hard
- ④ Electrically insulator
- ⑤ Brittle. (Can be break).
- ⑥ Malleable (Can be shaped). (Tensile).

Covalent Bond → These bond are form by sharing of e^- b/w neighbouring atom. Ex- Si, Ge, CO_2

General char of material having Co-valent bond →

- ① Very hard
- Very brittle

③ Very high melting Point.

④ Conductor \rightarrow Tin (Sn)

Semi-Cond \rightarrow Si, Ge.

Insulator \rightarrow Diamond.

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③ Metallic bond \rightarrow The outer most e^- of metal atom are weakly bound &

~~being~~ When such atom interact to become a solid these electron form a gas of electron known as electron gas or electron cloud

The Valence electron in a metal can't be associated with a particular atom. They belong to all atom.

General char of \rightarrow

(i) Higher thermal & electric property

(ii) Metals are opaque.

(iii) They are having surface luster.

(iv) Metallic bonds are non-directional. (It means bond strength is equal in all direction)

The highest degree of metallic bonding occurs in alkali metal.

~~both type of bonding~~

Vander - Waal bonding → An electron revolving around ~~strong~~ ⁽⁸⁾ nucleus may be considered to represent a rotating dipole.

→ Such a dipole will induce a dipole in a neighbouring atom such that a dipole attraction b/w the atom results.

These weaker bonds are Vander waal bonds

Ex- Solid Ar, Solid He, Solid hydrogen.

Inert Or Rare Gas → are example of Vander waal bonding.

→ Hydrogen bond is a strong type of Vander waal bonding.

Atomic arrangements in Solids.

- Crystallinity
- Single Crystal.
- Poly-Crystalline material.
- Amorphous.
- Epitaxial.

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→ Crystallinity —

Property of Solid in which atoms or molecule are stabed in a regularly or ordinary manner

→ Single Crystal →

→ If the atom are stabbed in regular manner then it is called single crystal.

Ex - Quartz.

→ These materials are unisotropic. (Property of material varies with direction)

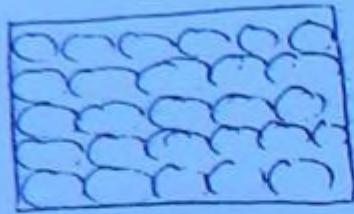
Poly Crystalline material →

It consist of Grains with in which atomic molecula with essentially regular but showing irregularities

as one goes from one grain to another.

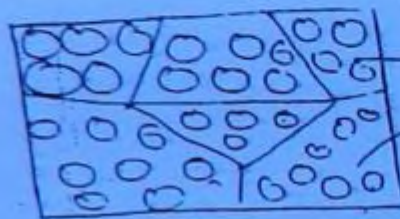
→ These material are generally isotropic because of random distribution of grains.

Single Crystal : —



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Poly-crystal Material →



Grain

Amorphous : —

Atoms of two first nearest neighbouring atoms are arranged periodically but the atom which are away from the nearest atom are found to be arranged randomly.

When the atoms are not given opportunity to arrange themselves in an orderly manner by inhibiting mobility during solidification, Amorphous material may be formed.

Ex Super cooled states of SiO_2 , correspond to glass (Amorphous material)

→ Where as upon Annealing (slower heating & cooling) may crystallise into quartz.

In other cases the molecules may be extremely long and irregular in shape so that orderly arrangement may not obtain as in the case of polymer. (//)

(5) Epitaxial \rightarrow (Used for growth of Si)

It refers growth of a layer of Si on a Substrate.

Structure of Solids

(1) Unit Cell \rightarrow Minimum area cell in 2 dimension
Or minimum volume cell in 3-d.
by repetition of which crystalline solid may be generated

Important properties of unit cell \rightarrow

(1) Cell dimension

(2) Angle b/w axis

(3) No. of atoms per unit cell.

(4) Co-ordination no. (It is no of atoms which are in physical contact with a particular atom.)

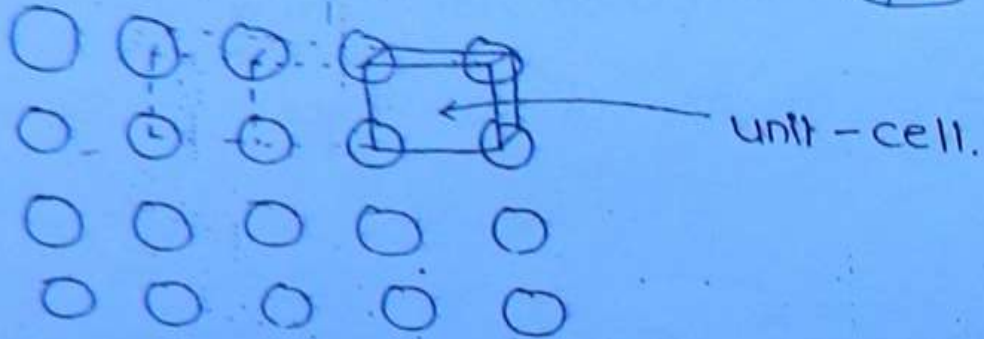
(5) Atomic packing factor (APF) —

$$= \frac{\text{Sum of total atomic Volume of per unit-cell}}{\text{Volume of unit cell.}}$$

Lattice →

Orderly or periodical arrangement of unit cell is called lattice.

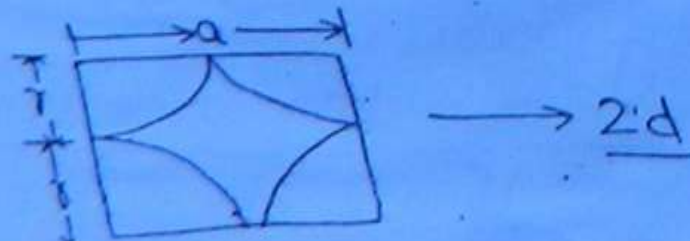
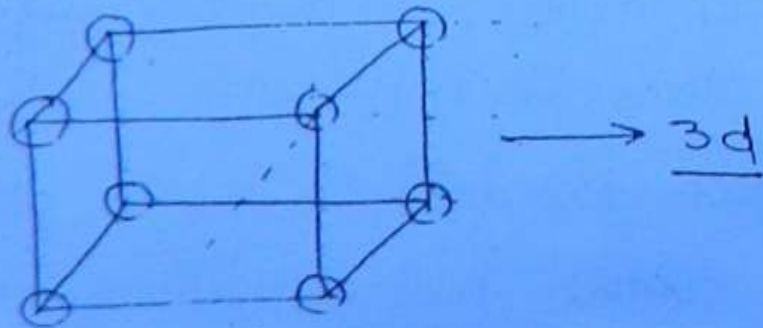
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Cubic - Crystal Structure →

- Diamond Cubic (DC)
- Simple Cubic (SC)
- Face Centred Cubic (FCC)
- Body Centred Cubic (BCC)

(1) Simple Cubic →

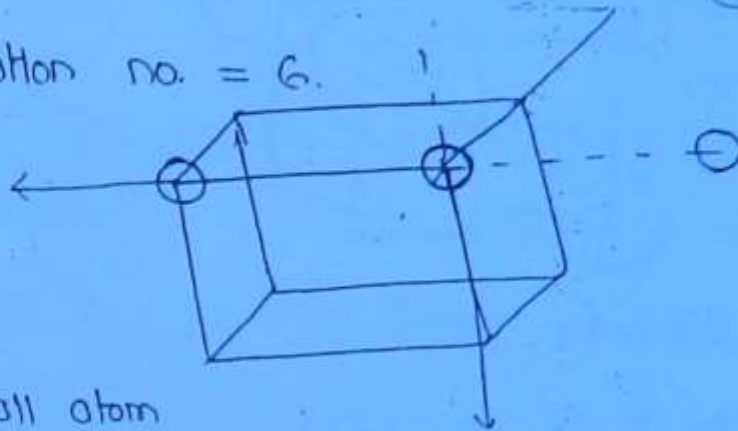


no. of atoms per unit cell = $8 \times \frac{1}{8} = 1$

In simple cubic there are 8 atoms at 8-corners of the cube.

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→ Co-ordination no. = 6.



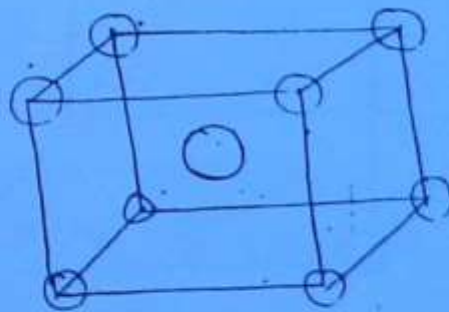
In x-axis all atoms will be same line.

→ $APF = \frac{1 \times \frac{4}{3} \pi r^3}{a^3} = 0.52$

$C = 2r$

Ex— Polonium, fluorapatite, Mn.

(2) BCC →



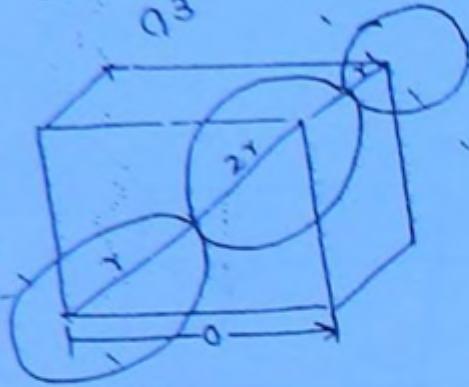
In case of BCC there are 8 atoms at 8 corners of cube and one atom at the centre of unit cell.

No of atoms per unit cell = $8 \times \frac{1}{8} \times 1$
 $= 2$

→ Co-ordination no. = 8

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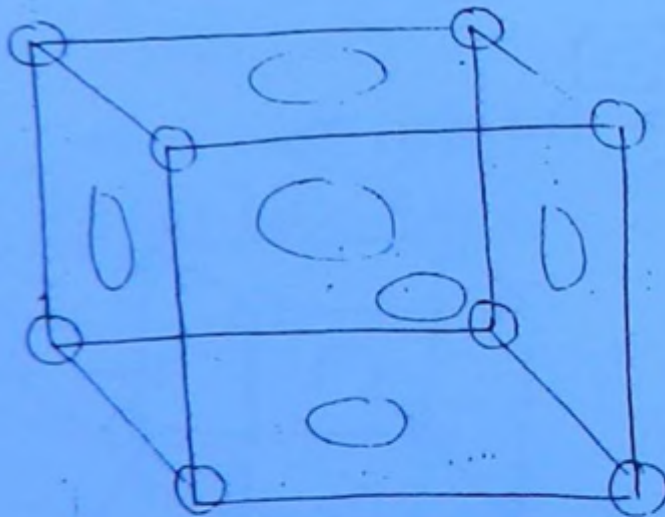
$$\rightarrow APF = \frac{2 \times \frac{4}{3} \pi r^3}{a^3} = .68$$



$$a\sqrt{3} = 4r$$

Ex- Li, Na, K, Cr, Fe (α -iron, δ -iron)

3) FCC →



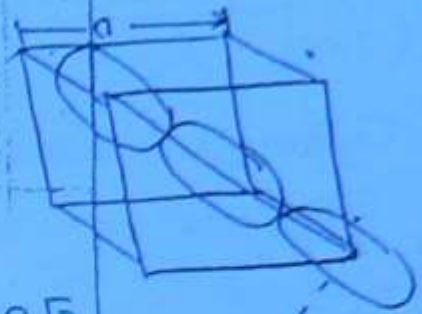
In FCC there are 8 atom and 8 corner at the cube and 6 atom at the centre of 6 faces of the cube.

$$\begin{aligned} \text{No. of atom per unit cell} &= 8 \times \frac{1}{8} + 6 \times \frac{1}{2} \\ &= 4 \end{aligned}$$

Co-ordination no - 12

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$$APF = \frac{4 \times \frac{4}{3} \pi r^3}{a^3} = 0.74$$



Ex - Au, Ag, Cu, Ni, Pt, Pb
Fe (γ -iron).

$$4r = 0.5a$$

NOTE - APF should be high.

Statement \rightarrow FCC is also known as cubic closed packed (CCP).

14) Diamond Cubic \rightarrow (Total 18 atom)

8 atoms at the ^{8 corner} of the cube

6 atoms at the centre of 6 faces of the cube

4 atoms are inside unit cell

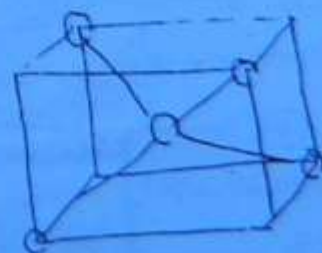
$$\rightarrow \text{no. of atoms per unit cell} = 8 \times \frac{1}{8} + 6 \times \frac{1}{2} + 4 = 8$$

Diamond Cubic is tetrahedral structure

\rightarrow Co-ordination no = 4

$$\rightarrow APF = 0.34$$

$$r = \frac{0.35a}{4}$$



→ This structure also called Zinc blende structure (Zns)

→ Group-3,5 Compound are having this type of structure

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5) Hexagonal - Closed packing (HCP) :-

→ APF = 0.74

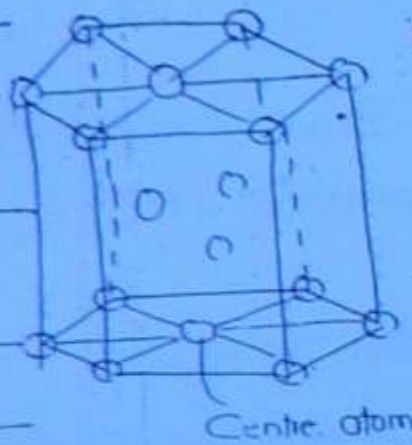
(Layer) B

(Layer) A

B

A

A



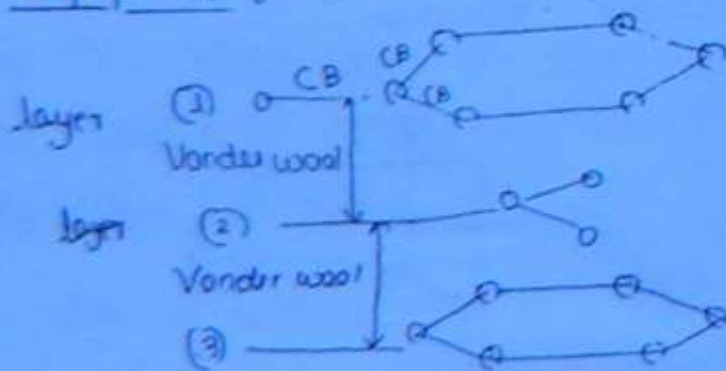
(It means central atom present in hexagonal)

→ no. of atom per unit cell = $3 + 2 \times \frac{1}{2} + 12 \times \frac{1}{6}$
= 6

→ Co-ordination no. = 12

6) Graphite :-

Vander wool - weak bond



① Graphite is having hexagonal crystal structure but it is not HCP as there are no centre atom available in the hexagonal.

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② Each C-atom has 4 valence electron 3 of these valence electron are used in forming covalent \bar{e} with adjacent atom in this 2D layer. The 4th \bar{e} is free to ~~wander~~ ^{wander} over the surface of the layer making graphite an electrical conductor.

→ Weak bonding forces within layer are called van der Waals forces because these forces are weak the layers can easily slide ~~past~~ pass each other.

→ The sliding of each other gives graphite its softness for writing and its lubricating property.

Ex- (HCP) — Be, Zn, Mg, Cd, Co

Comparison b/w diamond & Graphite →

	Diamond	Graphite
(1) Hard/Soft	Very hard	Soft
(2) Structure	Tetrahedral	hexagonal
(3) Elec. properties	Insulator	Conductor
(4) Thermal "	Conductor	Insulator
(5) Transparency	transparent	opaque

Comparison b/w Crystal Structure :- (18)

	No. of atoms/unit Cell	Co-ordination	APF	Atomic Radius (r)	Ex.
DC	8	4	.34	$\frac{0.43}{8}$	diamond, Si, Ge, C
SC	1	6	.52	$\frac{a}{2}$	Polonium, Fluorapatite, Mn
BCC	2	8	.68	$\frac{0.43}{4}$	Li, Na, K, Cr, Fe (α , δ)
FCC	4	12	.74	$\frac{0.43}{4}$	Au, Ag, Ni, Cu, Al, Pt, Pb
HCP	6	12	.74		Be, Zn, Mg, Cd, Co

$$\frac{C}{a} = \frac{\text{Max}^m \text{ dimension}}{\text{Min}^m \text{ dimension}} = \underline{\underline{1.63}}$$

Imperfections in Solid :-

- Point defect ✓
- Line
- Surface
- Volume

X

There are two types of point defect

(i) Vacancy :- A Vacancy is a point defect which involve missing atom within a crystal.



Vacancy defect

Schottky defect is a vacancy defect in which a pair of anion and cation is missing from crystal structure.

Ex- $\text{Na}^+ \text{Cl}^-$ missing

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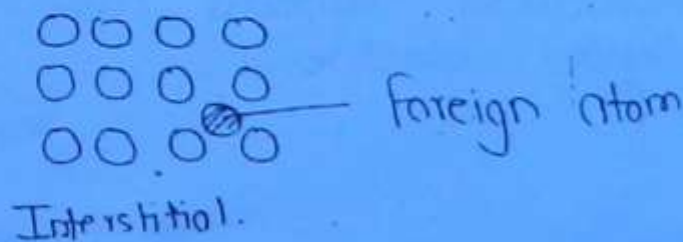
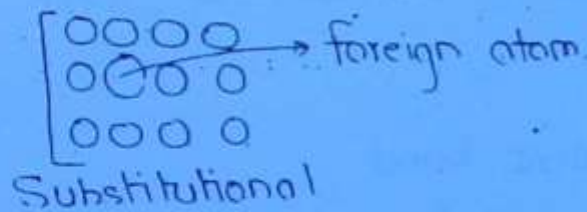
② Impurity defects : —

→ Substitutional

→ Interstitial

(i) Substitutional → This defect refers to a foreign atom which substitutes or replaces a parent atom in the crystal.

An interstitial impurity is a small sized atom occupying a wide space in the parent crystal.



2) In a crystal lattice the vacancy created by the absence of certain atom are known as

- (a) Frenkel defect
- (b) Frenkel's "
- (c) Crystal
- ~~or~~ Schottky

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3) The crystal in which atoms are chemically highly inactive and they do not form compound with other atom

- (a) Ionic crystal
- (b) Metal
- ~~or~~ Vander Waals crystal \rightarrow (due to Inert Gas.)
- (c) Valence crystal
Crystal having covalent bond

4) Group-3,5 semiconductor compound have which one of following crystal structure.

- (a) BCC
- (b) FCC
- (c) Hexagonal
- ~~or~~ Zinc Blende

④ When BCC iron is heated it change to FCC iron resulting in.

(a) Increase the volume

(b) Contraction in volume.

(c) no change in "

(d) Crack in the material.

density \uparrow

BCC \longrightarrow FCC

APF - 0.68

APF - 0.74

$$APF = \frac{\text{Volume of atoms in unit cell}}{\text{Volume of unit cell}}$$

Dielectric Properties of Material (22)

Dielectric :- A dielectric is a non conducting material which can be polarized by an electric field.

* If main funⁿ of non conducting material is charge storage then it is called dielectric.

* If main funⁿ of non conducting material is to provide electrical insulation then it is called insulator.

Parameters of dielectric →

- dielectric Constant (ϵ)
- dipole moment (p)
- Polarization (P)
- Polarizability (α)

1) dielectric Constant → It is defined as the ratio of electric flux density to electric field intensity.

$$\epsilon = \frac{D}{E}$$

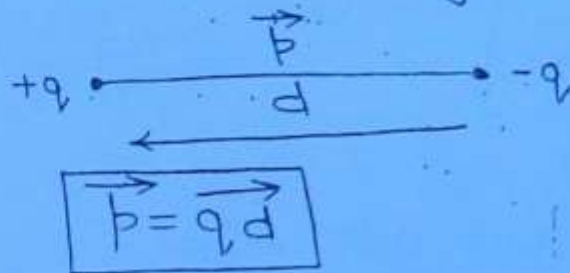
Where ϵ - dielectric Constant
 $= \epsilon_0 \epsilon_r$

ϵ_0 - permittivity of free space $= 8.85 \times 10^{-12}$ F/m
 ϵ_r - Relative permittivity

(2) Dipole-moment \rightarrow Two opposite charges separated by a distance constitute an electric dipole. (23)

* Dipole moment is defined as the product of charge and distance of separation.

* It is a vector quantity, which is directed from negative to positive charge.



Unit :- (1) Coulomb-m.

(2) 1 Debye. $= 3.33 \times 10^{-30} \text{ C-m}$.

NOTE -

$$\boxed{D = \epsilon E}$$

The above relation is applicable only to isotropic material. (Materials in which the dielectric and other physical properties are independent of the direction in which they are measured).

\rightarrow Polycrystalline material with a random distribution of grains is non-directional (Isotropic).

\rightarrow So the above relation can be used for this material.

\rightarrow Single crystal materials are anisotropic. So one can't use the above relation.

* For unisotropic materials dielectric constant should be replaced by 'Tensor' quantity in above relation.

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3) Polarisation \rightarrow It is defined as dipole moment per unit volume.

$$\vec{P} = \frac{\vec{p}}{\text{Volume}}$$

Unit -

$$P = \frac{Qd}{V} \rightarrow Q/m^2$$

$$= Np$$

N = no. of dipoles per unit volume.

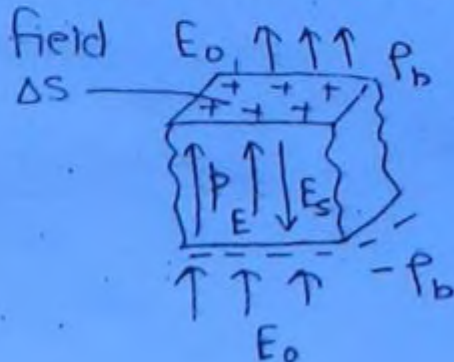
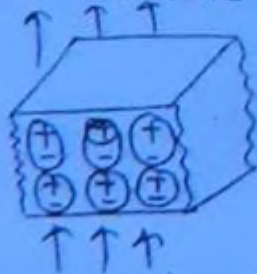
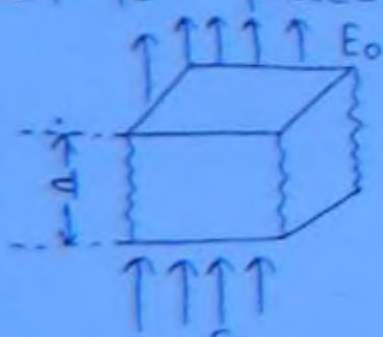
Relation b/w polarisation and electric field \rightarrow

In dielectric material bound charges are predominant under the application of applied electric field.

The bound electron are displaced the centroid of electron cloud is separated from the centroid of nucleus. Then atom is said to be polarised.

This phenomenon is called electronic polarisation.

Let us consider a dielectric slab of thickness, d , is placed in an electric field E_0 .



all the charges except at the boundary of dielectric. (25)

** Thus the net result is the formation of +ve surface charge at the top surface and (-ve) surface charge at the bottom surface.

$$\begin{aligned} P &= \frac{P}{\text{Vol.}} \\ &= \frac{Q \cdot d}{\Delta S \cdot d} \\ &= \frac{P_b \cdot \Delta S}{\Delta S} = P_b \end{aligned}$$

* The surface charge distribution produces secondary electric field E_s (opposite to \vec{P})
 $\rightarrow E_s = \frac{P_b}{\epsilon_0}$ (Surface charge density)

Total electric field inside dielectric.

$$\begin{aligned} E &= E_0 - E_s \\ &= E_0 - \frac{P_b}{\epsilon_0} \end{aligned}$$

$$E = E_0 - \frac{P}{\epsilon_0}$$

$$\epsilon_0 E = \epsilon_0 E_0 - P$$

$$\epsilon_0 E_0 = \epsilon_0 E + P = D$$

$$D = \epsilon_0 E + P$$

$$\epsilon E = \epsilon_0 E + P$$

$$\epsilon_0 \epsilon_r E = \epsilon_0 E + P$$

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Dielectric Strength & Dielectric breakdown

In any material the field intensity can not be increase indefinitely.

→ When a high electric field is applied across a dielectric material, a considerable no. of e^- may get excited to the energy levels with in conduction band.

→ As a result of this the current through dielectric increases & cause localized melting, burning and vaporization of dielectric material leading to irreversible degradable. & may even failure of material.

→ It result in high electrical conductivity and total loss of charge storage property of dielectric.

→ This phenomenon is called dielectric breakdown.

→ Dielectric strength represent the magnitude of applied electric field necessary to produce breakdown.

→ It is also define as the max^m potential gradient that

Which dielectric is subjected to electric field.

- Moisture, Contamination ^(to make impure) increased temp. and mechanical stress usually tends to decrease the dielectric strength.

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Mechanism of Polarization :-

- Electronic / Induced polarization
- Ionic / Molecular "
- Orientational "
- space charge / Interfacial "

(1) Electronic / Induced polarization :-

Electronic polarization

- result from the displacement of the centroid of negatively charge e^- cloud relative to the centroid of positively charge nucleus in an atom by an applied electric field.

This type of polarization is found in the material in which there is no interaction b/w the atom or molecule.

Ex - Inert Gases. (Gr-A)

$$\begin{aligned} \alpha_e &= \text{electronic - polarizability} \\ &= 4\pi\epsilon_0 R^3 \end{aligned}$$

$$\alpha_{\text{He}} < \alpha_{\text{Ne}} < \alpha_{\text{Ar}} < \alpha_{\text{Kr}}$$

Induced Polarization ----

$$P_{ind} = N P_{ind} \\ = N \alpha_e E$$

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$$\epsilon_0 \chi_e E = N (4\pi \epsilon_0 R^3) E$$

$$\epsilon_0 (\epsilon_r - 1) = N 4\pi \epsilon_0 R^3$$

$$\boxed{\epsilon_r = 1 + 4\pi N R^3}$$

** Electronic polarization is independent of Temp.

Qw:- The no of dipole in volume of 1 cubic m of hydrogen gas is 9.8×10^{26} the radius of the hydrogen atom is $.53 \text{ \AA}$ calculate α_e, ϵ_r

Solⁿ

$$\epsilon_r = 1 + 4\pi N R^3$$

$$\epsilon_r = 1 + 4\pi \times 9.8 \times 10^{26} \times (.53 \times 10^{-10})^3 \\ = \underline{1.0018}$$

$$\alpha_e = 4\pi \epsilon_0 R^3 \\ = 4\pi \times 8.85 \times 10^{-12} \times (.53 \times 10^{-10})^3 \\ = 1.66 \times 10^{-41} \text{ F-m}^2$$

2) Ionic Polarization :- This type of polarization occurs in ionic material

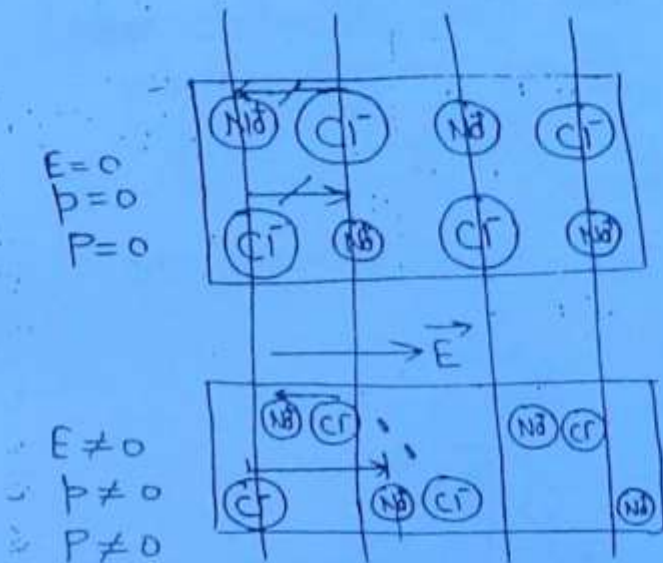
In which cations and anions get displaced

- in opposite direction.
- i.e. Alkali halides (NaCl).

(29)

* Ionic polarizability measures the shift of ions relative to each other.

* Ionic polarization is also independent of temp.



Induced dipole moment —

$$P_{\text{ind}} = \alpha_i \cdot E$$

↑
ionic polarizability

Total Polarization: $P = P_e + P_i$

$$= N(\alpha_e + \alpha_i)E$$

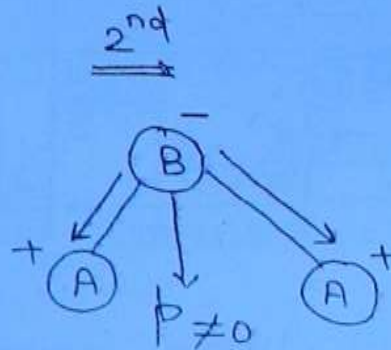
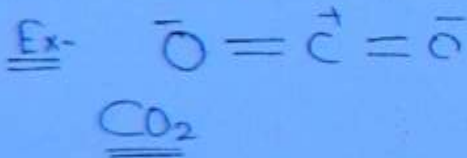
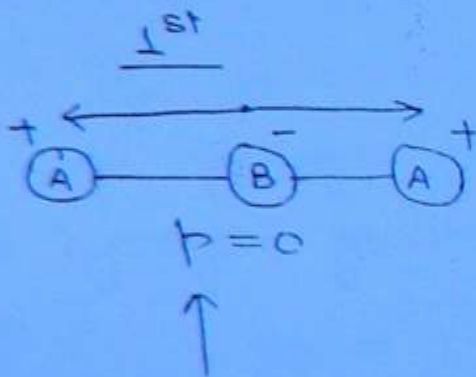
- * For most of material the ionic polarizability is less than the electronic polarizability. In general

$$\boxed{\alpha_i = \frac{\alpha_e}{10}} \quad \begin{array}{l} \text{Electronic} \\ \uparrow \\ \text{Ionic} \end{array}$$

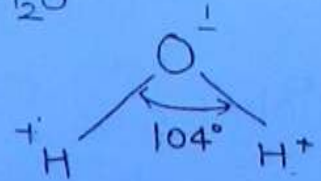
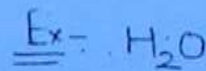
(30)

3) Orientation Polarization \rightarrow This type of Polarization is found in the material having Partial ionic bond or covalent bond.

i.e. CH_3Cl , CO , NO , NO_2 , H_2O , Nitrobenzene etc



dipole moment due to orientation of molecule is called permanent dipole moment.



These material causes permanent dipole moment even in the absence of external electric field.

Orientation polarization is given by

$$\rightarrow P_o = \frac{N P_p^2}{3KT} E$$

Where P_p - permanent dipole moment

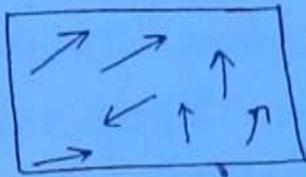
$$P_o = N \alpha_o E$$

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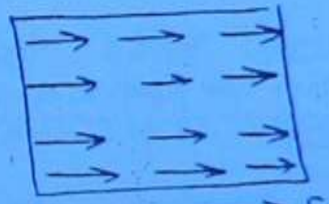
$$\alpha_o = \frac{P_p^2}{3KT}$$

$$\alpha_o \propto \frac{1}{T}$$

NOTE Orientational Pol. is inversely proportional to temp and directly proportional to the square of the permanent dipole moment.



$E=0$



$E \neq 0$

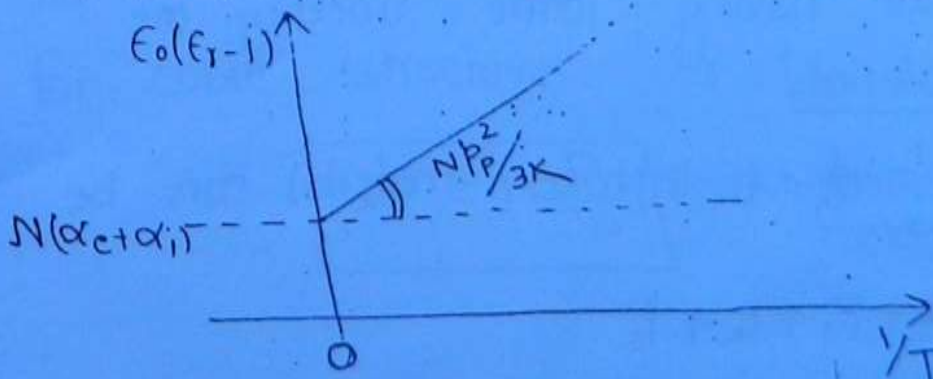
Total Polarization :-

$$P = P_i + P_e + P_o$$

$$P = N[\alpha_e + \alpha_i + \alpha_o]E$$

$$\epsilon_o(\epsilon_r - 1)E = N\left[\alpha_e + \alpha_i + \frac{P_p^2}{3KT}\right]E$$

$$\epsilon_o(\epsilon_r - 1) = N\left[\alpha_e + \alpha_i + \frac{P_p^2}{3KT}\right]$$



When $1/T = 0$

(4) Space-charge / Interfacial Polarization : — (32)

In this type of polarization is the result of lattice vacancy or impurity centre present in the dielectric.

The three mechanism of polarization discussed above all due to charge that are locally bound in the atoms or molecules in the structure of solids or liquids.

In addition some free charge carriers also exist that can ^(travel from one region to another) migrate for some distance through dielectric. Free charge carrier migrating through the crystal under the influence of electric field may be trapped by defects such as lattice vacancies or impurity centre.

The effect of this will be a localized accumulation of charges which will induce its image charge on the electrodes and gives rise to dipole moment. This type of polarization called space charge polarization.

Such material having lattice vacancy are called 'multiphase material'.

The total Polarization, of multiphase material can be given by —

$$P_T = P_e + P_i + P_o + P_s$$

↙ Total Polarization.

In case of single phase material —

$$P_T = P_e + P_i + P_o$$

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Internal field in Solids : — In case of gases, we

assume that the internal

field is equal to the applied electric field and as long as the density of molecule is reasonably low, this is a good approximation.

Highly in solid & liquid the molecules & atom are so closed together that the field seen by them is the result of the field due to dipoles and the external field.

Where — $E_i = E + \frac{\gamma}{\epsilon_0} P$

E_i — internal field

E — external "

γ — internal field constant

γ is a unit less quantity and depend upon the structure.

for cubic structure $\gamma = \frac{1}{3}$

$$E_i = E + \frac{P}{3\epsilon_0}$$

Lorentz internal field.

Classification of solid on the basis of their dielectric behaviour \rightarrow (34)

- (1) Elemental dielectric Solid.
- (2) Ionic non-polar solid.
- (3) Polar Solid.

(1) Elemental dielectric Solid — These are the solids which possess only electronic polarization. These solids consist of only single type of atom.
Ex- ~~Ge~~ Ge, Si, diamond, S.

Measurement of dielectric constant for Solids:-

$$\rightarrow E_i = E + \frac{\gamma}{\epsilon_0} P \quad \text{--- (I)}$$

$$\rightarrow P = N \alpha_e E_i \quad \text{--- (II)}$$

$$P = N \alpha_e \left[E + \frac{\gamma}{\epsilon_0} P \right]$$

$$\rightarrow P = \frac{N \alpha_e}{1 - \frac{N \alpha_e \gamma}{\epsilon_0}} \cdot E$$

$$P = \epsilon_0 \chi_e E$$

$$\frac{N \alpha_e}{1 - \frac{N \alpha_e \gamma}{\epsilon_0}} = \epsilon_0 \chi_e$$

$$\epsilon_r - 1 = \frac{\left(\frac{N\alpha_e}{\epsilon_0} \right)}{1 - \left(\frac{N\alpha_e}{\epsilon_0} \right) \gamma} \quad \text{--- (A)}$$

(35)

$$\boxed{\epsilon_r = \frac{1 - (\gamma - 1) \left(\frac{N\alpha_e}{\epsilon_0} \right)}{1 - \gamma \left(\frac{N\alpha_e}{\epsilon_0} \right)}} \quad \text{--- (B)}$$

Imp. for Conventional —

C.M Equation (Clausius-Mossotti eqⁿ) — This eqⁿ is applicable for

the materials having cubical structure (having ~~long~~ ^{no} internal field).

$$\rightarrow \gamma = 1/3$$

$$\rightarrow E_i = E + \frac{P}{3\epsilon_0}$$

from eqⁿ no. (A)

$$\epsilon_r - 1 = \frac{\frac{N\alpha_e}{\epsilon_0}}{1 - \frac{N\alpha_e}{3\epsilon_0}}$$

$$\epsilon_r + 2 = \frac{\frac{N\alpha_e}{\epsilon_0}}{1 - \frac{N\alpha_e}{3\epsilon_0}} + 3$$

$$\epsilon_r + 2 = \frac{3}{1 - \frac{N\alpha_e}{3\epsilon_0}}$$

$$\boxed{\frac{\epsilon_r - 1}{\epsilon_r + 2} = \frac{N\alpha_e}{3\epsilon_0}} \quad \text{--- CM Eqⁿ}$$

for gases state
 $\epsilon_r \approx 1$

(36)

$$\frac{\epsilon_r - 1}{\beta} = \frac{N \alpha_e}{\beta \epsilon_0}$$

$$\epsilon_0 (\epsilon_r - 1) = N \alpha_e$$

$$\epsilon_0 \chi_e = N \alpha_e$$

$$\boxed{\alpha_e = \frac{\epsilon_0 \chi_e}{N}}$$

Maxwell relation \rightarrow

Relation b/w refractive index and relative permittivity of dielectric -

$$\eta = \frac{c}{v} = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = \frac{1}{\left(\frac{1}{\sqrt{\mu_0 \epsilon}}\right)}$$

$$\eta = \frac{1}{\sqrt{\mu_0 \epsilon_0}} \sqrt{\mu_0 \mu_r \epsilon_0 \epsilon_r}$$

$$\eta = \sqrt{\mu_r \epsilon_r}$$

for dielectric

$$\mu_r = 1$$

$$\boxed{\epsilon_r = \eta^2}$$

Debye's generalization of cm eq -

It is applicable only for gases state for gases.

$$N = \frac{N_A \cdot \rho}{M}$$

(37)

M - Molecular weight (kg)

ρ - molecular density (kg/m³)

N_A - Avogadro no.
 $= 6.023 \times 10^{23}$

$$\begin{aligned} \rightarrow \frac{\epsilon_r - 1}{\epsilon_r + 2} &= \frac{N \alpha_e}{3 \epsilon_0} \\ &= \left(\frac{N_A \rho}{M} \right) \cdot \frac{\alpha_e}{3 \epsilon_0} \end{aligned}$$

$$\boxed{\frac{N_A \cdot \alpha_e}{3 \epsilon_0} = \frac{\epsilon_r - 1}{\epsilon_r + 2} \cdot \frac{M}{\rho}}$$

Lorentz - Lorentz Equation \rightarrow

$$\epsilon_r = \eta^2$$

$$\boxed{\frac{N_A \alpha_e}{3 \epsilon_0} = \frac{\eta^2 - 1}{\eta^2 + 2} \cdot \frac{M}{\rho}}$$

This Equation is applicable for gases having electronic polarization.

Ex - Inert Gases

(2) Ionic Non-polar Solid \rightarrow These are the Solids which possess electronic as well as ionic polarization.

Ex- Alkali halide

(38)

* They do not have permanent dipole moment.

* Total Polarization

$$P_T = P_e + P_i$$

$$P = N[\alpha_e + \alpha_i] E$$

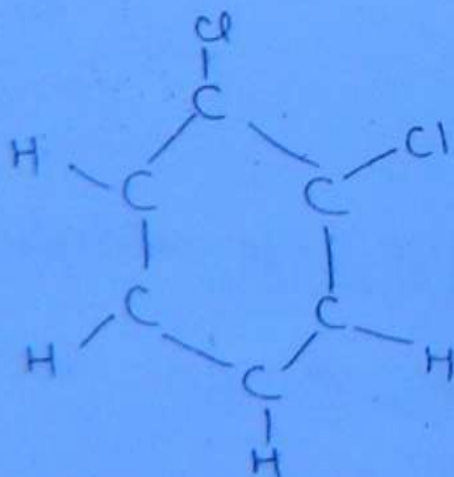
(3) Polar Solid \rightarrow These are the solid which possess electronic, ionic as well as orientation polarization.

* These solid consist of dissimilar atoms having partial ionic bond.

* These solids possess permanent dipole moment.

Ex- Nitrobenzene, ortho & meta dichloro benzene

Ortho-dichloro benzene —



Not symmetry
So permanent
dipole.

Classification of dielectric on the basis of their dielectric behaviour in Electric field. →

(39)

→ Piezo-electric.

↳ charge generation by mechanical field & converse

→ Pyro electric

↳ charge generation by thermal field & Converse.

→ ferro electric

↳ charge generation by electric field & converse

→ Anti ferro-electric.

(1) Piezo electric material → Some material get polarized when they

are subjected to a mechanical stress. Such material are called piezo electric mat & this property of material is called Piezo electricity.

When these material are subjected to an electric field the material gets strained.

* The strain produced is proportional to the applied electric field.

$$\boxed{\text{Strain} \propto E}$$

There are two types of effect in Piezo electricity

① Direct Effect → Generation of electric charge from a mech. stress.

Application — Microphone, Gas lighter.

(40)

② Inverse Effect → Generation of strain due to applied electric field

App — Quartz Watches.

Examples of Piezo electric materials →

- ① Quartz
- ② Barium Titanate (BaTiO_3)
- ③ Lead Titanate (PbTiO_3)
- ④ Lead Zirconate (PbZrO_3)
- ⑤ Potassium dihydrogen phosphate (KDP)
- ⑥ Ammonium dihydrogen phosphate (ADP)
- ⑦ lead zirconate titanate (PZT)
- ⑧ Rochelle Salt

Application of Piezo electric material →

- 1) Filter
- 2) Oscillators
- 3) Resonators
- 4) Ultra sonic flow detector
- 5) Quartz Watches

Electrostriction : — Some material gets strain when they are subjected to an electric field but converse is not true. (4)

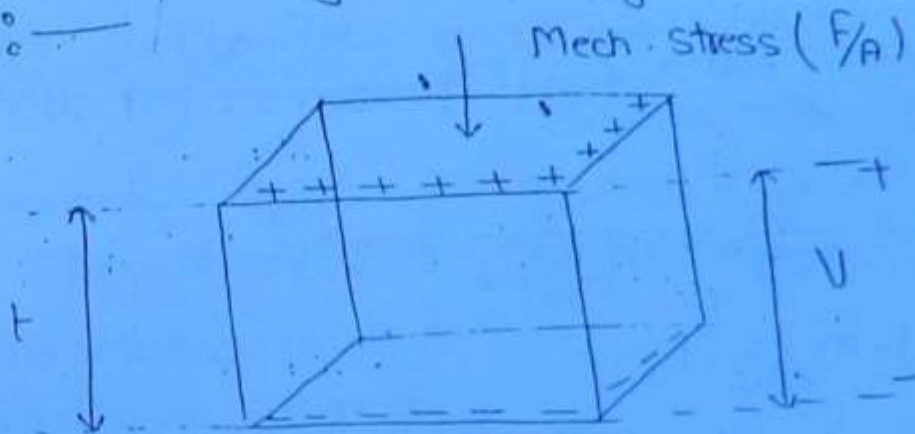
* This property of material is called electrostriction.

The strain produced in the material is proportional to the square of electric field.

$$\text{Strain} \propto E^2$$

**

Expression for Voltage sensitivity of Piezo electric material : —



Produced charge -

$$Q \propto F$$

$$Q = d \cdot F$$

Where d = charge - sensitivity
Unit $\rightarrow (C/N)$

$$CV = dF$$

$$V = \frac{dF}{C}$$

$$= \frac{d \cdot f}{\epsilon A}$$

$$= \left(\frac{f}{A}\right) \cdot \left(\frac{d}{\epsilon}\right) \cdot t$$

(42)

$$V = P g t$$

Where g = Volt Sensitivity

$$= \frac{d}{\epsilon}$$

$$= \frac{V}{P \cdot t}$$

$$= \frac{E}{P}$$

Voltage Sensitivity \rightarrow It is defined as electric field produced per unit mech.

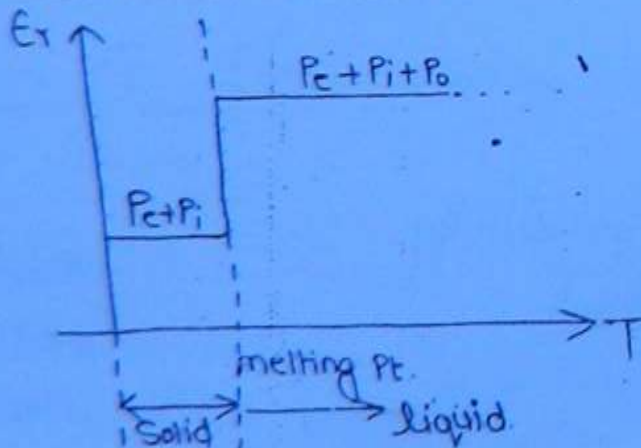
stree.

Unit — $g = \frac{V}{P \cdot t} = \frac{V}{\left(\frac{F}{A}\right) \cdot t} = \frac{V \cdot A}{F \cdot t}$

$$V - m/N$$

18/02

Some Important Point \rightarrow



E_r vs T Curve for Nitrobenzene.

① * Polar Solids contain's permanent dipoles but these are frozen in the solid state and can no longer be aligned by the external field. (43)

* Thus for polar solid one can measure only electronic & ionic polarization.

(ii) In Liquid state dielectric constant decreases with increasing Temp. due to the fact that orientational Polarization decrease with increases temp.

(iii) In Solids dielectric constant is independent of temp. but in liquids and gases it decreases with increasing temp.

Spontaneous Polarization : — Certain dielectrics exhibits the properties of spontaneous Polar. it means non-zero polarization even in the absence of external electric field.

Ex- ferro electric material
Pyro electric material.

$$P = N\alpha E_i$$

$$= N\alpha \left(E + \frac{\gamma}{\epsilon_0} P \right)$$

$$P = \frac{N\alpha E \rightarrow 0}{1 - \frac{N\alpha\gamma}{\epsilon_0} = 0}$$

↙ ≠ 0

We want $P \neq 0$ So
Condⁿ is $\frac{\gamma}{\epsilon_0}$ should be 0.

for spontaneous polarization

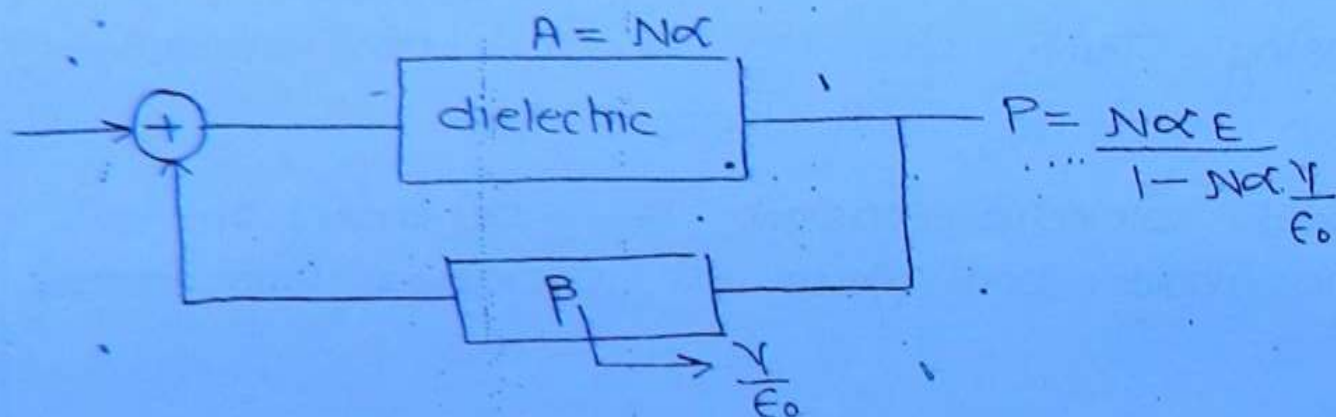
$$E = 0 \quad P \neq 0$$

for this value of denominator should be zero.

$$1 - \frac{N\alpha\gamma}{\epsilon_0} = 0$$

(44)

$$\boxed{\frac{N\alpha\gamma}{\epsilon_0} = 1}$$



The above sys represents a closed loop system with (+ve) f.b having

$$\boxed{G_{pfa} = N\alpha}$$

$$F/b \text{ factor} = \beta = \frac{\gamma}{\epsilon_0}$$

for +ve f.b

$$A\beta = 1$$

$$\frac{N\alpha\gamma}{\epsilon_0} = 1$$

2

Pyro electric material \rightarrow * Polarization of material by a change in material is

called Pyro electricity.

* These are material which possess spontaneous Polarization

* The direction of polarization can not be reverse by reversing the direction of electric field.

* The Polarization of these material changes with change in temp.

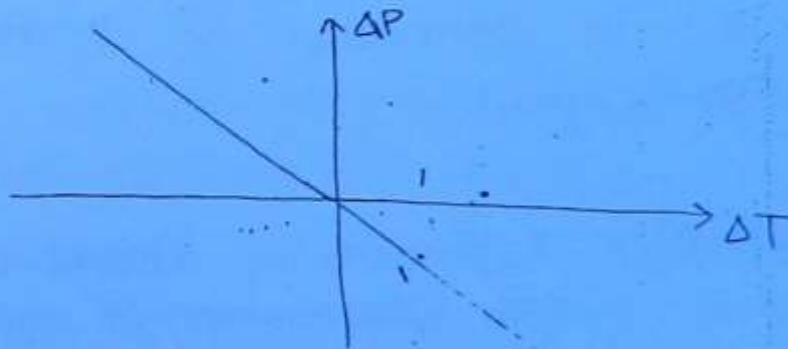
(45)

$$\Rightarrow \begin{array}{l} T \uparrow \rightarrow P \downarrow \\ T \downarrow \rightarrow P \uparrow \end{array}$$

$$\Delta P = \lambda \cdot \Delta T$$

temp. coefficient of Polarization

λ - is negative Quantity.



Ex - BaTiO_3 . Tourmaline

* Pyroelectricity is the ability of certain material to generate a temporary Voltage, when they are heated or cool.

* The change in temp. modifies the positions of the atoms in the crystal structure such that the polarization of material changes. This polarization change gives.

rise to a Voltage across the crystal. If the temp stays constant at its new value the (46) Pyroelectric Voltage gradually disappears due to leakage Current.

→ Pyroelectricity should not be confused with thermoelectricity.

→ In Pyroelectricity the whole crystal is changed from one temp. to another temp. and result is temporary Voltage across the ~~terminal~~ crystal.

→ In thermoelectricity one side of material is kept at one temp. and the other side is kept at different temp. & the result is generation of permanent Voltage across the crystal.

3) ferroelectric material → ferroelectric material shows the phenomenon of hysteresis.

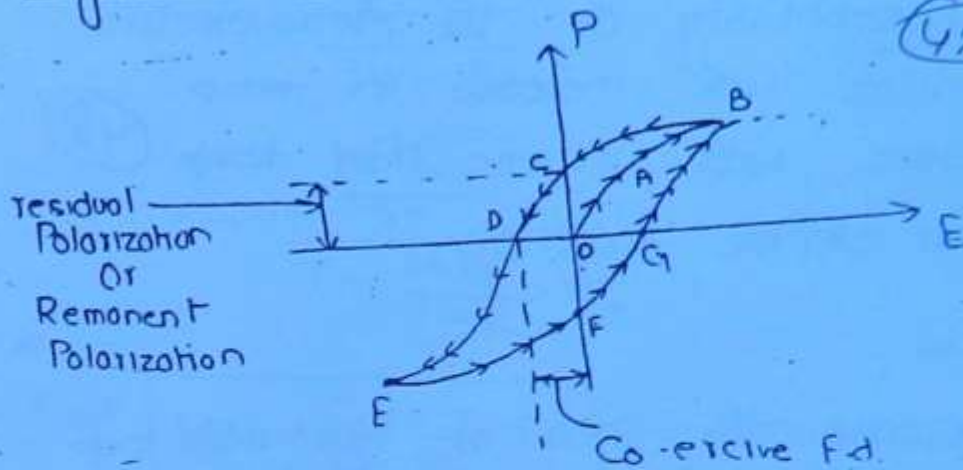
These material exhibits spontaneous polarization even in the absence of external field.

* The direction of polarization can be reverse by reversing the direction of electric field.

The ferroelectric material remain ferroelectric upto a critical temp. called ~~Querry~~ "Curie" temp. and above Curie temp the material start behaving like Piezoelectric material.

Hysteresis Curve →

(47)

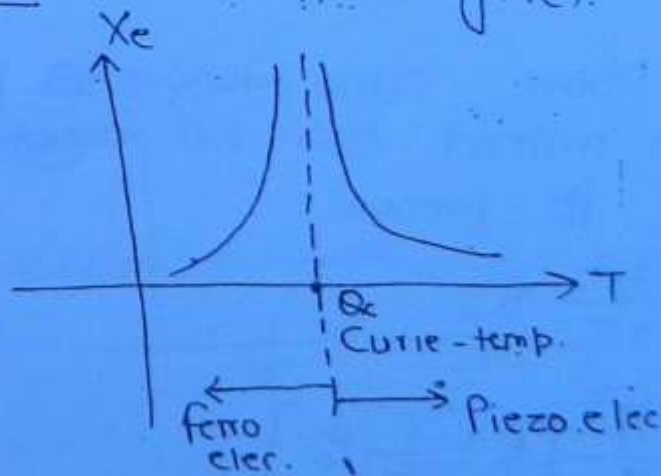


* When a ferroelectric material is subjected to an external field the material follows the path OAB in the hysteresis curve the material remains polarized even at the external field is reduced to zero.

* This residual value of polarization (OC) is called Residual Or Remanent Polarization

* To reduce the residual polarization to zero, an electric field is applied in the reverse direction. This field is called co-ercive field.

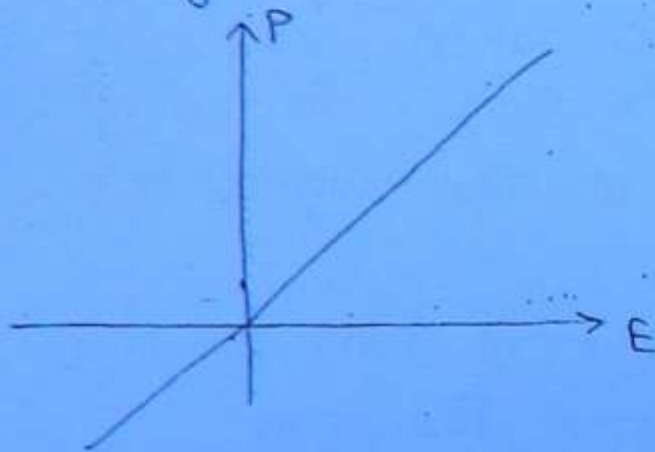
χ_e Vs T → (Susceptibility χ_e).



→ The electric susceptibility of the ferroelectric material increases with increase in temp whereas it decreases with increase in temp in case of Piezo electric material. (48)

Above Curie-temp →

When temp is increase the area of hysteresis loop decreases and at critical temp. called Curie temp. hysteresis loop merges in two straight line.



For Piezo electric material.

Above Curie-temp the relationship b/w Polarization and electric field is governed by Curie-Weiss law.

Curie-Weiss law → Above Curie temp. the polarization in material can be assumed to be orientational polarization it means

$$P_0 = \frac{N P_p^2}{3KT} E_i$$

$$= \frac{N P_p^2}{3KT} \left[E + \frac{\gamma}{\epsilon_0} P_0 \right]$$

$$P = \frac{\frac{N p_p^2}{3KT}}{1 - \frac{N p_p^2}{3KT} \cdot \frac{\gamma}{\epsilon_0}} E$$

(49)

$$= \frac{\frac{N p_p^2}{3K}}{T - \frac{N p_p^2}{3K} \cdot \frac{\gamma}{\epsilon_0}} E$$

$$P = \frac{C \epsilon_0}{T - \theta} E \quad \rightarrow \text{Curie-Weiss law.}$$

Where

θ - Curie-temp.

$$= \frac{N p_p^2}{3K} \cdot \frac{\gamma}{\epsilon_0}$$

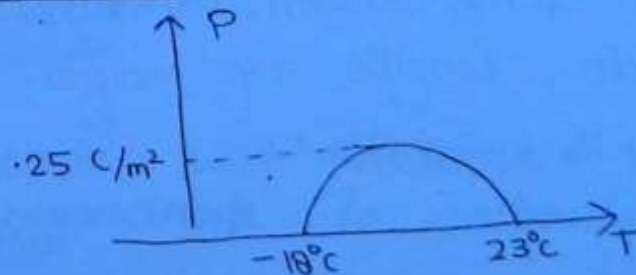
$$C = \frac{\theta}{\gamma} = \text{Curie-const.}$$

$$\gamma = \frac{\theta}{C} = \text{internal field constant}$$

Ex-1. Rochelle Salt

2. BaTiO_3
3. PbTiO_3
4. Sodium Nitrate
5. KDP
6. Alums (फिटकरी)

Rochelle Salt :-

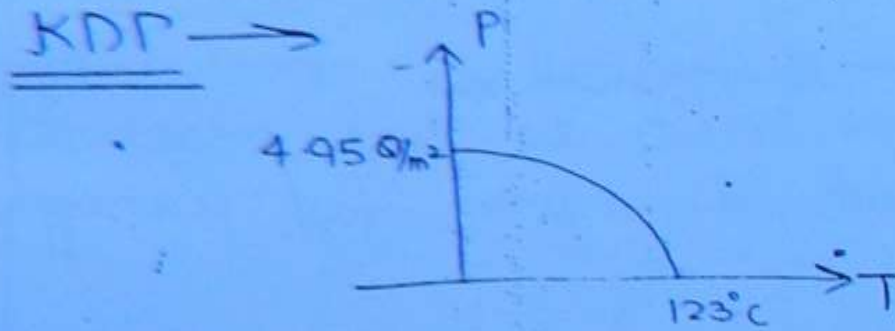


* Rochelle Salt is first ~~available~~ ever discovered ferroelectric material

(56)

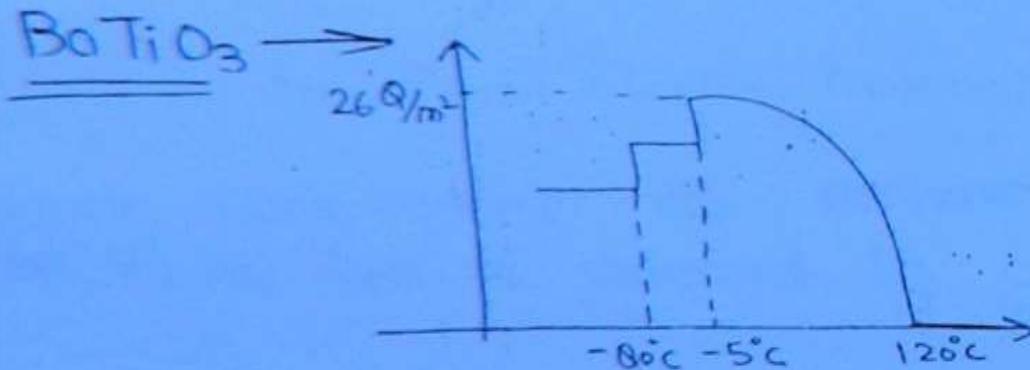
* It has two Curie-temp at (-18°C) & (23°C)

* Spontaneous polarization : 25 C/m^2



* Curie temp is 123°C .

* Spontaneous polarization is 4.95 C/m^2



* S. Polar should high

* BaTiO₃ is best known ferroelectric material

* Curie temp is 130°C

* Spontaneous polarization is 26 C/m^2

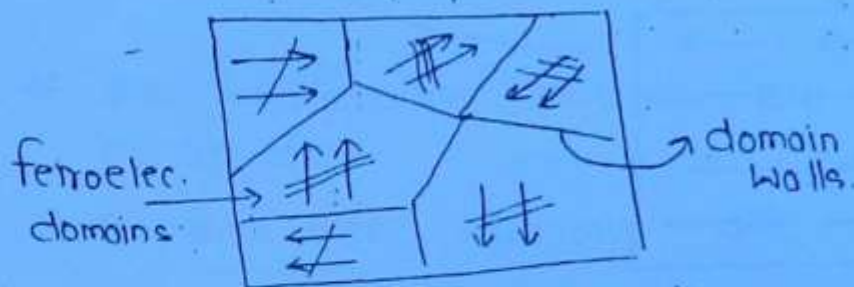
* It has 6 possible direction of spontaneous Polarization.

It have highest ionic Polarizability because

- *Titanium ion has charge of (+4) unit.
- *It can be displaced over a relatively larger distance.

(5)

ferro Electric domains



ferroelectric materials.

Each ferroelectric material is divided into small region each region is spontaneously polarize with uniform direction of polarization.

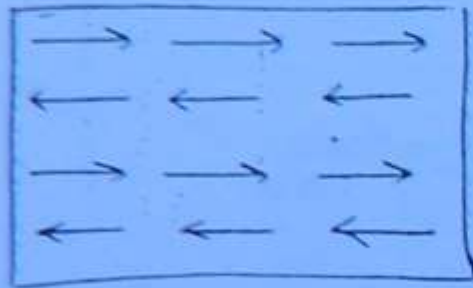
The direction of polarization varies from one region to other region. these region are called ferro electric domain.

The boundary separating the ferroelectric domain are known as domain walls.

When an external field is applied, the dipoles of all the region get aligned along the external field and domain wall collapse resulting in the increasing Polarization.

The path (OAB) of hysteresis curve shows collapsing of domain walls & growth of single domain having all the dipoles in same direction. (52)

Antiferro electric material →

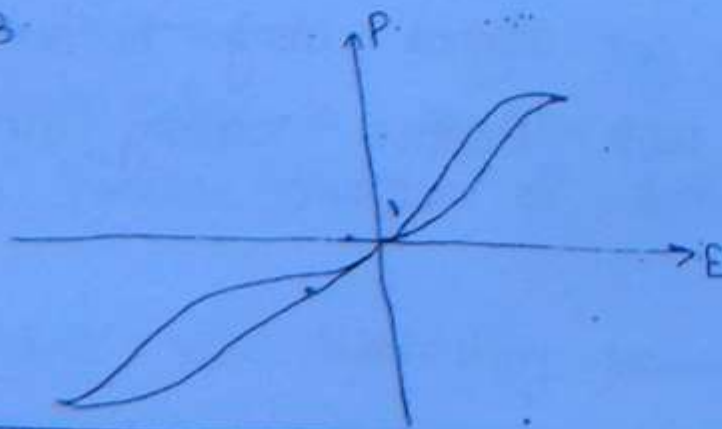


- * These are the material which possess zero spontaneous polarization.
- * The dipoles are aligned in anti parallel direction.
- * These materials are antiferro electric upto a critical temp called curie temp & above curie temp these starts behaving like piezo electric materials.

Ex Sodium Niobate.

ADP

PbZrO_3





(53)

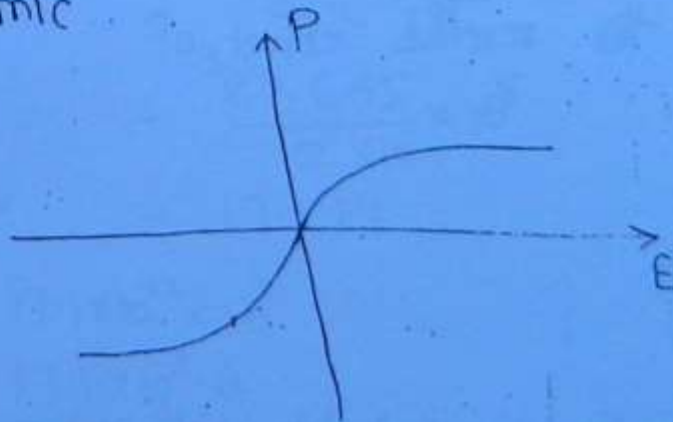
- * All ferro electric materials are Pyro as well as piezo elec.
- * All Pyro elec. materials are Piezo electric.

Para electric material → These material posses zero spontaneous material

they have dipole but unaligned.

Under the influence of electric field these dipole aligned resulting in the generation of Polarization of in the material.

Ex Ceramic



Consider the following statement related to Piezoelectric material and their effect. (54)

- 1) Stress applied to the material produces electronic Polarization
 - 2) An electric field applied to the material produces strain in it
 - 3) All Piezo elec. materials are ferroelectric material.
- Which of these statements are correct.

Consider the following statement

In a ferroelectric material

- 1) All domains are aligned in the direction of electric field giving rise to saturation Polarization (spontaneous polarization)
- 2) If field is reduced to 0, many domains remain aligned
- 3) The residual Polarization can be eliminated only if material is heated above temp. (We can also with reverse electric field)

* Piezoelectricity is the reverse effect of

- (a) Peltier effect
- (b) Hall effect
- (c) Electroluminescence
- 1) Electrostriction

Ques:- In a solid or liquid dielectric with externally applied electric field E , as the inter atomic distances increase the internal field.

(i) Increases

(ii) decreases

(c) Remain unaltered

(d) Increases or decrease based on temp.

$$E_i = E + \frac{\gamma}{\epsilon_0} P$$
$$= E + \frac{\gamma}{\epsilon_0} (N \propto E_i)$$

$$\downarrow E_i = \frac{E}{\left[1 - \left(\frac{\gamma N}{\epsilon_0}\right) \downarrow\right]} \uparrow$$

Que:- Consider a Parallel Plate Capacitor having an area of $6.45 \times 10^{-4} \text{ m}^2$ and a plate separation of $2 \times 10^{-3} \text{ m}$ across, which a potential of 10 V is applied. If a material is having a dielectric const. of 6.0 is positioned within the region b/w the plates calculate

(i) C

(ii) Q

(iii) D

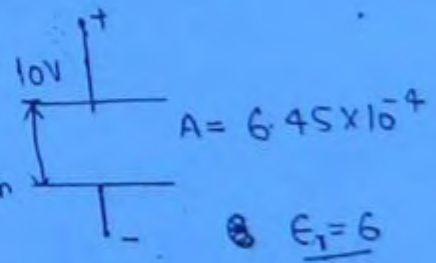
(iv) P

$$\textcircled{1} C = \frac{\epsilon A}{d}$$

$$= \frac{6 \times 6.45 \times 10^{-4} \times 8.85 \times 10^{-12}}{2 \times 10^{-3}}$$

$$= \frac{3 \times 6 \times 6.45}{2 \times 10} \times 10^{-5}$$

$$= 17.1 \text{ PF}$$



$$\epsilon = \epsilon_r \epsilon_0$$

$$\textcircled{II} Q = 17.1 \times 10^{-12} \times 10$$
$$= 17.1 \times 10^{-11} \text{ C}$$

$$\begin{aligned}
 \textcircled{m} \quad D &= \epsilon E \\
 &= \epsilon_0 \epsilon_r \left(\frac{V}{d} \right) \\
 &= 8.85 \times 10^{-12} \times \frac{6 \times 10}{2 \times 10^{-3}} \\
 &= 2.66 \times 10^{-7} \text{ C/m}^2
 \end{aligned}$$

(56)

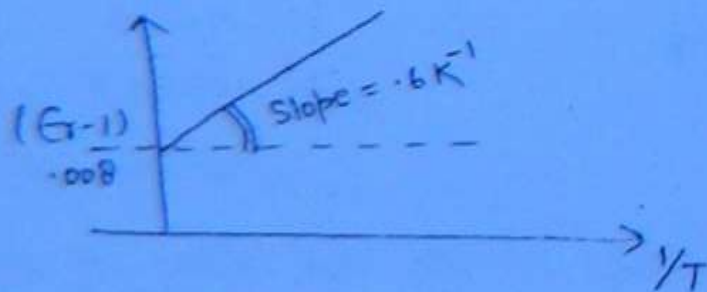
$$\begin{aligned}
 \textcircled{n} \quad P &= \epsilon_0 \chi_e E \\
 &= \epsilon_0 (\epsilon_r - 1) E \\
 &= 2.22 \times 10^{-7} \text{ C/m}^2
 \end{aligned}$$

Que:- Calculate the voltage generated across the piezo electric material of thickness 1 cm when a mech. stress of 10 N/m^2 is applied.

(Given $g = \text{Vol. Sensitivity} = 23 \times 10^3 \text{ Vm/N}$)

$$\begin{aligned}
 V &= P \cdot g \cdot t \\
 &= 10 \times 23 \times 10^3 \times 10^{-2} \\
 &= 2300
 \end{aligned}$$

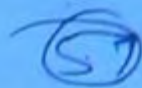
Que:- The Variation of the dielectric constant of $\text{C}_6\text{H}_5\text{N}$ as a fun of temp. are plotted in the figure. Calculate the permanent dipole moment of molecules if no. of molecules per meter³ is 2.5×10^{25}



~~$\epsilon_r = \epsilon_0 (\epsilon_r - 1)$~~

$$\epsilon_0 (\epsilon_r - 1) = N \left[\alpha_e + \alpha_i + \frac{P_p^2}{3kT} \right]$$

$$\text{Slope} = \frac{N p_p^2}{3 K \epsilon_0} = .6 K^{-1}$$



$$p_p^2 = \frac{3 \times .6 K \epsilon_0}{2.5 \times 10^{25}}$$

$$= \frac{3 \times .6 \times 1.38 \times 10^{-23} \times 0.85 \times 10^{-12}}{2.5 \times 10^{25}}$$

$$= 2.68 \times 10^{-30} \text{ Q-m}$$

Que:- A homogeneous slab of lossless dielectric material is char by an electric susceptibility of 0.12 & carries a uniform elec. flux density within it of 1.6 nC/m^2 . Find elec. field intensity, polarization, dipole moment if there are 2×10^{19} dipoles/ m^3 & the voltage b/w the equipotential 2.54 cm apart surface.

Solⁿ

$$X_e = .12$$

$$N p = 2 \times 10^{19} / \text{m}^3$$

$$D = 1.6 \frac{\text{nC}}{\text{m}^2}$$

$$d = 2.54 \text{ cm}$$

$$E = ?, P, p \text{ \& } V$$

$$X_e = \epsilon_r - 1$$

$$\epsilon_r = 1.12$$

$$E = \frac{D}{\epsilon} = \frac{D}{\epsilon_0 \epsilon_r} = \frac{1.6 \times 10^{-9}}{0.85 \times 10^{-12} \times 1.12}$$

$$= 161.4 \text{ V/m}$$

$$P = \epsilon_0 X_e E$$

$$= 0.85 \times 10^{-12} \times 0.12 \times 161.4$$

$$= 1.71 \times 10^{-30} \text{ Q/m}^2$$

$$p = \frac{P}{N}$$

$$= \frac{1.71 \times 10^{10}}{8.55 \times 10^{19}} = 0.55 \times 10^{-30} \text{ C-m.}$$

(58)

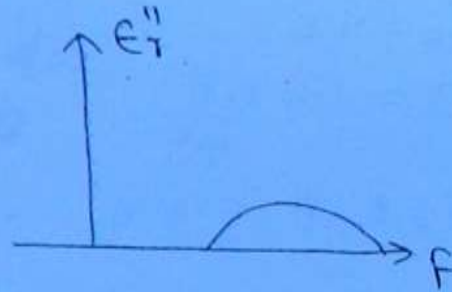
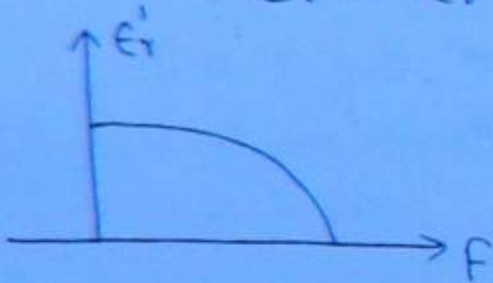
$$U = E \cdot d$$

$$= 161.4 \times 2.54 \times 10^{-2}$$

$$= 4.1 \text{ V.}$$

Dielectric in AC field :- When an a.c field is applied, the dielectric constant which was real for static field, breaks into real and imaginary part.

$$\epsilon_r = \epsilon_r' - j\epsilon_r''$$



* Real part of dielectric constant decreases with increase in freq.

* Imaginary part of dielectric constant 1st increase, attains a maximum value then decreases with increasing freq.

At a lower freq. real part is dominant and at higher freq. imaginary part of dielectric constant is dominant.

Dielectric loss :- The absorption of electrical energy by a dielectric material subjected to an a.c field is known as dielectric loss. The result, in dissipation of electrical energy in the form of heat in the material.

It occurs due to two regions. (59)

- (i) Oscillation of losses.
- (ii) Continuous change in the orientation of dipole.

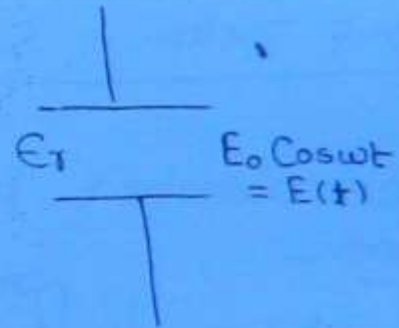
derivation of Energy loss :-

$$\epsilon_r = \epsilon_r' - j\epsilon_r''$$

$$D = \epsilon E(t)$$

$$= \epsilon E_0 \cos \omega t$$

$$= \text{Re} [\epsilon E_0 e^{j\omega t}]$$



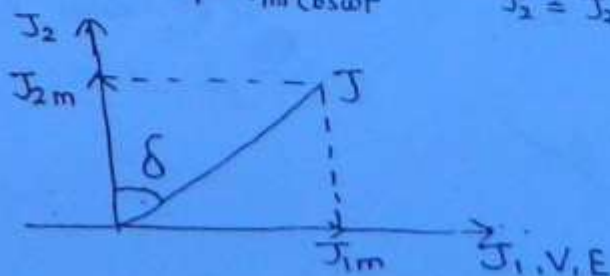
$$J = \text{Current density} = \frac{d}{dt} [D]$$

$$= \text{Re} [\epsilon_0 \epsilon_r E_0 j\omega e^{j\omega t}]$$

$$J = \text{Re} [\epsilon_0 (\epsilon_r' - j\epsilon_r'') E_0 j\omega (\cos \omega t + j \sin \omega t)]$$

$$= \epsilon_0 E_0 \omega [\epsilon_r'' \cos \omega t - \epsilon_r' \sin \omega t]$$

$$= \underbrace{\epsilon_0 E_0 \omega \epsilon_r'' \cos \omega t}_{J_1 = J_{1m} \cos \omega t} + \underbrace{\epsilon_0 E_0 \omega \epsilon_r' \cos(\frac{\pi}{2} + \omega t)}_{J_2 = J_{2m} \cos(\frac{\pi}{2} + \omega t)}$$



δ - loss angle

$$\tan \delta = \text{loss tangent} \\ = J_{1m} / J_{2m}$$

$$= \frac{\epsilon_0 \epsilon_0 \omega \epsilon_r''}{\epsilon_0 \epsilon_0 \omega \epsilon_r'}$$

$$\tan \delta = \frac{\epsilon_r''}{\epsilon_r'}$$

Obj - for most of the dielectric materials.

$$.0001 \leq \tan \delta \leq .001$$

$$\text{Loss factor} - \epsilon_r' \tan \delta = \epsilon_r''$$

Power absorbed per unit volume in one time period -

$$W = \frac{1}{2\pi} \int_0^{2\pi} J E(t) \cdot d(\omega t) \\ = \frac{1}{2\pi} \int_0^{2\pi} E_0 \cos \omega t \cdot \epsilon_0 \epsilon_0 \omega (\epsilon_r'' \cos \omega t - \epsilon_r' \sin \omega t) d\omega t$$

$$W = \frac{1}{2\pi} \epsilon_0 \epsilon_0^2 \omega \int_0^{2\pi} [\epsilon_r'' \cos^2 \omega t - \epsilon_r' \cos \omega t \cdot \sin \omega t] d\omega t \\ \left(\frac{1 - \cos 2\omega t}{2} \right)$$

किसी भी sinusoidal fun
की Avg. value 0 होती है,

$$W = \frac{1}{2\pi} \epsilon_0 \epsilon_0^2 \omega \cdot \frac{\epsilon_r''}{2} \cdot 2\pi$$

$$W = \frac{1}{2} \epsilon_0 \epsilon_0^2 \omega \epsilon_r'' \quad \text{Watt/m}^3$$

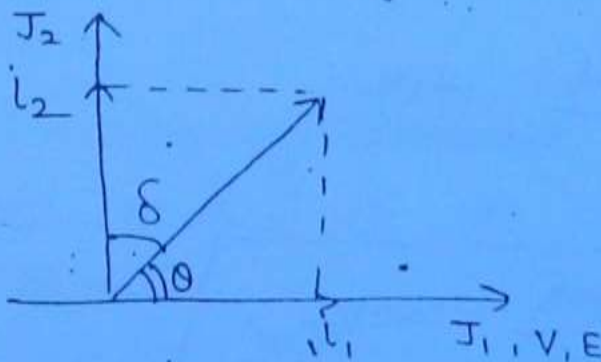
$$W \propto \epsilon_r''$$

$$\propto \omega$$

$$\propto \epsilon_0^2$$

Energy absorbed by dielectric from a.c field is proportional to imaginary part of dielectric constant

Loss Calculation using circuit Analysis :-



$$\begin{aligned} \text{Power loss} &= V i \cos \theta \\ &= V i \cos (90^\circ - \delta) \\ &= V i \sin \delta \end{aligned}$$

$$\left[\cos \delta = \frac{i_2}{i} \Rightarrow i = \frac{i_2}{\cos \delta} \right]$$

$$\begin{aligned} P_L &= V \cdot \frac{i_2}{\cos \delta} \cdot \sin \delta \\ &= V \cdot i_2 \tan \delta \end{aligned}$$

$$P_L = V \cdot i_c \cdot \tan \delta$$

$$= V \left(\frac{V}{X_c} \right) \cdot \tan \delta$$

(62)

$$P_L = V^2 \cdot 2\pi f C \cdot \tan \delta \rightarrow \text{Watt}$$

$$= (E_0 d)^2 \cdot 2\pi f \left(\frac{\epsilon_0 A}{d} \right) \cdot \tan \delta$$

$$P_L = E_0^2 \cdot 2\pi f \epsilon (A \cdot d) \cdot \tan \delta$$

$$\frac{P_L}{Ad} = E_0^2 \cdot 2\pi f \epsilon \cdot \tan \delta$$

$$= \frac{E_0^2 \cdot f \cdot \epsilon_r \cdot \tan \delta}{\left(\frac{1}{2\pi \epsilon_0} \right)} \quad \text{Watt/m}^3$$

$$\frac{P_L}{\text{Vol.}} = \frac{E_0^2 \cdot f \cdot \epsilon_r \cdot \tan \delta}{1.8 \times 10^{12}} \quad \text{Watt/cm}^3$$

Que:- A Solid specimen of dielectric has $\epsilon_r = 4.2$ & $\tan \delta = .001$ at 50Hz. If it is subjected on electrical stress of 50 KV/cm what is the heat generated in the specimen due to dielectric stress?

- (a) 291 W/cm³ (b) 5.02 mW/cm³
 (c) 19.5 W/cm³ ~~(d)~~ 291 mW/cm³

Consider the following statement regarding an insulating material connected to a.c. Voltage.

① The dielectric constant increase with f (63)

② " " " decreases " "

③ Atomic polarization

$$\rightarrow \downarrow \alpha = \frac{\epsilon_0 \chi_e}{N} = \frac{\epsilon_0 (\epsilon_r - 1)}{N} \downarrow \downarrow P = N \alpha \downarrow E$$

NOTE - dielectric Constant of solid dielectric in the a.c. field is maximum at Power freq. and decreases to unity, at freq. in ultra violet range.

Consider the following statement

① The dielectric constant of an insulator depends on

① Applied Voltage

② freq. of a.c. field

③ Temp. $\rightarrow \alpha = \frac{\epsilon_0 \chi_e}{N} = \frac{\epsilon_0 (\epsilon_r - 1)}{N} \propto \frac{P_p^2}{3kT}$

④ Max^m Current density in insulator.

20/02

Effect of frequency on polarization :—

① Space charge polarization is effective upto power audio freq. (100Hz)

S. C. Polar. < 100Hz

② Orientation Polarization is effective upto ($10^6 - 10^{10}$ Hz).

iii) Ionic Polarization is effective upto infrared range
(10^4 Hz).

(64)

iv) Electronic Polarization is effective upto visible range
(5×10^{14} Hz).

Equation governing motion of \bar{e} in A.C field \rightarrow

$$m \frac{d^2x}{dt^2} + 2b \frac{dx}{dt} + ax = -eE_0 \cos \omega t$$

Where - m - mass of \bar{e} cloud
 $2b$ - damping Const.
 a - spring or force Constant

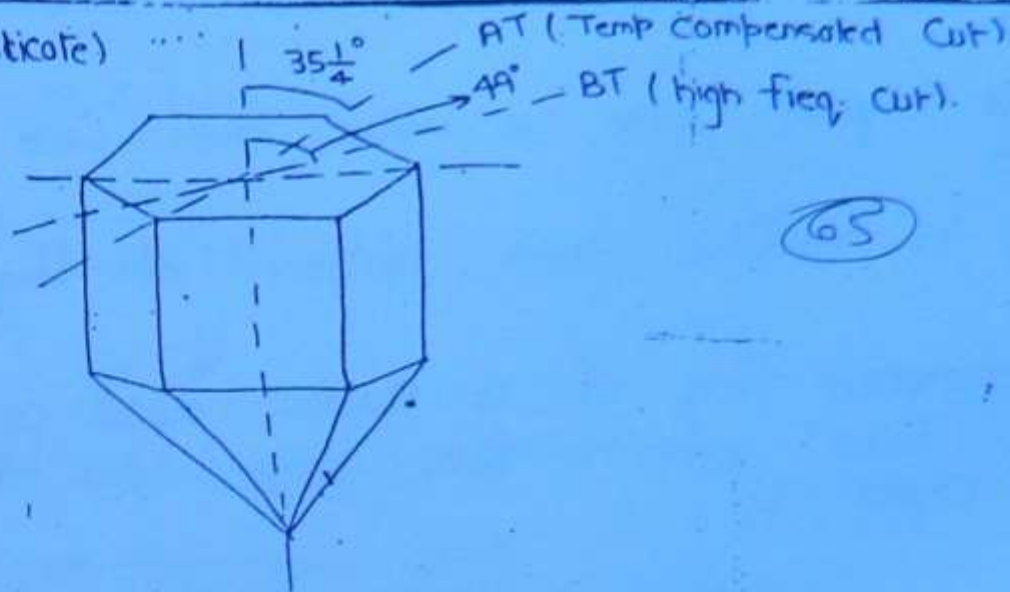
$E_0 \cos \omega t$ = A.C field

$$\omega_0 = \text{Resonant freq.} = \sqrt{\frac{a}{m}}$$

Quartz \rightarrow

- i) Quartz is a crystalline material
- ii) Structure is silicate tetrahedron (SiO_4)
- iii) Quality factor is in the range of 10^4 to 10^6
- iv) It has a shape of hexagonal prism with Pyramids attached to both ends.

→ SiO₂ (Silicate) ...



AT Cut → * Thin plate making an angle of 35.25° with Z axis.

- * It is most widely used cut.
- * high degree of freq. stability over wide temp. range
- * Sensitive to stress.

BT Cut Crystal →

- * It has poorer temp. char. than AT cut.
- * It can be used for crystals having higher freq. than AT cut.

Stress Compensated Cut → (SC)

In highly stable oscillator CKT AT cut quartz crystal are generally employed. What is the reason for using this particular orientation.

Quartz crystal has a natural growth along this plane. The corresponding quality factor is largest for this orientation.

iii) AT cut crystal can be used over wide freq. range

iv) There is minimal temp variation of freq. (66)

The resonance freq. of a Quartz crystal oscillator shows least variation with temp. when the orientation of the crystal is.

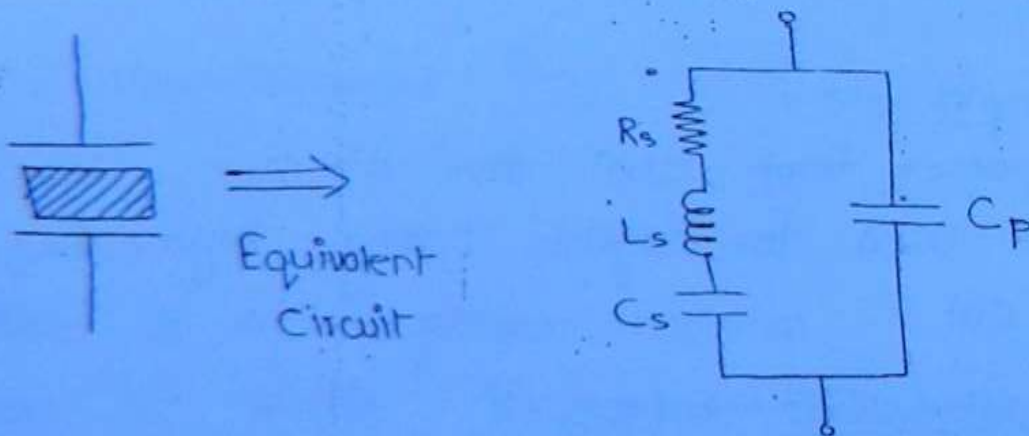
i) X Cut

ii) Y Cut

iii) NT Cut

iv) AT Cut

Equivalent circuit diagram of quartz crystal :-



Where - R_s - represent damping Const.
 L_s - " mass of crystal.
 C_s - " spring constant
 C_p - " electrostatic capacitance b/w opposite faces of crystal.

$$Z_s = R_s + j(\omega L_s - \frac{1}{\omega C_s})$$

$$Z_p = \frac{1}{j\omega C_p}$$

(67)

$$Y = \frac{1}{Z_s} + \frac{1}{Z_p}$$

$$= \frac{1}{R_s + j(\omega L_s - \frac{1}{\omega C_s})} + j\omega C_p$$

$$= \frac{R_s - j(\omega L_s - \frac{1}{\omega C_s})}{R_s^2 + (\omega L_s - \frac{1}{\omega C_s})^2} + j\omega C_p$$

$$Y = Y_{real} + Y_{imag}$$

$$= \frac{R_s}{R_s^2 + (\omega L_s - \frac{1}{\omega C_s})^2} + j \left[\omega C_p - \frac{(\omega L_s - \frac{1}{\omega C_s})}{R_s^2 + (\omega L_s - \frac{1}{\omega C_s})^2} \right]$$

for resonance -

$$Y_{imag} = 0$$

$$\omega C_p - \frac{(\omega L_s - \frac{1}{\omega C_s})}{R_s^2 + (\omega L_s - \frac{1}{\omega C_s})^2} = 0$$

$$\omega C_p [R_s^2 + (\omega L_s - \frac{1}{\omega C_s})^2] - (\omega L_s - \frac{1}{\omega C_s}) = 0$$

for higher amplitude of Oscillator

$$\boxed{R_s = 0}$$

$$\omega C_p \left[(\omega L_s - \frac{1}{\omega C_s}) - 1 \right] \left[\omega L_s - \frac{1}{\omega C_s} \right] = 0$$

$$(\omega L_s - \frac{1}{\omega C_s}) = 0 \text{ Or } \frac{1}{\omega C_p} \dots \textcircled{1}$$

68

For Series resonance —

$$Y_s = Y_{\text{real}} / \text{max.}$$

$$= \frac{R_s}{R_s^2 + (\omega L_s - \frac{1}{\omega C_s})^2} \downarrow \text{min.}$$

$$Y_s = \frac{1}{R_s}$$

$$\omega_s = \frac{1}{\sqrt{L_s C_s}}$$

For parallel - resonance →

$$Y_p = Y_{\text{real}} / \text{min}$$

$$= \frac{R_s}{R_s^2 + (\omega L_s - \frac{1}{\omega C_s})^2} \frac{1}{\omega_p C_p}$$

$$Y_p = \frac{R_s}{R_s^2 + (\frac{1}{\omega_p C_p})^2}$$

$$\omega_p L_s - \frac{1}{\omega_p C_s} = \frac{1}{\omega_p C_p}$$

$$\omega_p = \frac{1}{\sqrt{L_s C^1}}$$

where

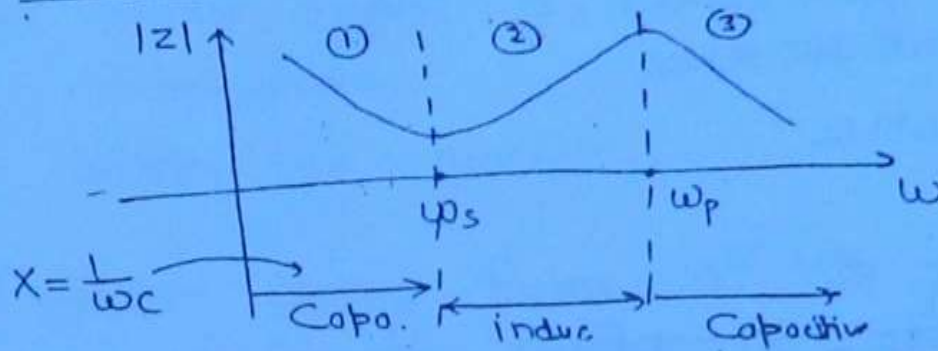
$$C^1 = \frac{C_s C_p}{C_s + C_p}$$

Relation b/w ' ω_s ' & ' ω_p ' \rightarrow

$$\omega_p = \omega_s \sqrt{1 + \frac{C_s}{C_p}}$$

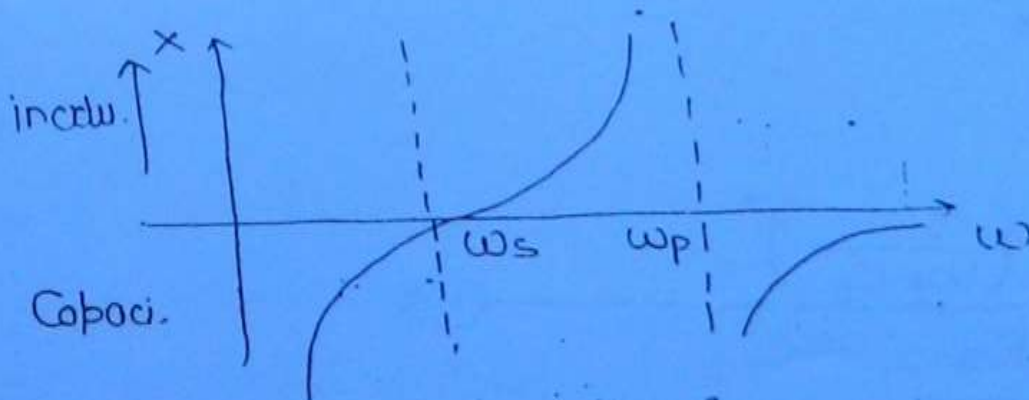
(69)

" $|Z|$ " Vrs ω Curve



- ① $\omega_p > \omega_s$
- ② When $\omega < \omega_s \rightarrow$ CKT is capacitive.
- ③ " $\omega_s < \omega < \omega_p \rightarrow$ " " inductive
- ④ " $\omega > \omega_p \Rightarrow$ " " Capacitive

\rightarrow "Reactance" Vrs " ω " curve \rightarrow



Que:- A Quartz Crystal has following char -

\rightarrow Series resonance freq. = 200 KHz.

\rightarrow Impedence at series resonance = 200 Ω .

\rightarrow Parallel resonance freq, = 200.25 KHz

Impedance at Parallel resonance = $40\text{M}\Omega$

determine the component values?

(70)

Solⁿ $f_s = f_p = 200\text{KHz} \Rightarrow \omega_s = 2\pi \times 200 \times 10^3$

$$R_s = 200\Omega$$

$$\omega_p = 200.25\text{KHz}$$

$$Z_p = 40\text{M}\Omega$$

$$\omega_s = \frac{1}{\sqrt{L_s C_s}}$$
$$200 \times 10^3 = \frac{1}{\sqrt{L_s C_s}} \quad \text{--- (i)}$$

$$\omega_p = \frac{C_s C_p}{\sqrt{L_s \left(\frac{C_s C_p}{C_s + C_p} \right)}} \quad \text{--- (ii)}$$

$$\frac{1}{40 \times 10^6} = \frac{200 \times 200}{(200)^2 + \left(\frac{1}{200.25 \times C_p} \right)^2}$$

$$\left(\frac{1}{200.25 \times C_p} \right)^2 =$$
$$C_p =$$

$$Z_p = \frac{R_s^2 + \left(\frac{1}{\omega_p C_p} \right)^2}{R_s} \quad \text{--- (iii)}$$

$$\omega_p = \omega_s \sqrt{1 + \frac{C_s}{C_p}} \quad \text{--- (iv)}$$

from (iii) $C_p = 0.08\text{PF}$

from (iv) $C_s = 0.022\text{PF}$

$$L_s = 28.48\text{H}$$

Consider the following statement related to Quartz crystal

(71)

- (a) Quartz display ferroelectric behaviour
- ~~(b) Quartz is used in electronic oscillator CRT.~~
- ~~(c) Quartz crystal is formed by repeating silicate tetrahedrons.~~

Which are correct.

Effective Quality factor of the equivalent electrical CRT of quartz crystal is of the order of.

- (a) 20
 - (b) 200
 - (c) 2000
 - ~~(d) 200,000~~
- ($10^4 - 10^6$)

Magnetic Properties of materials

(72)

→ Permeability

Magnetic dipole moment

Magnetization

Permeability →

It is defined as the ratio of mag. flux density and mag. field intensity.

$$\mu = \frac{B}{H}$$

Where - B - mag. flux density (wb/m²)

H - mag. field intensity (A/m)

$$\mu = \mu_0 \mu_r$$

Where $\mu_0 = 4\pi \times 10^{-7}$ H/m.

μ_r - relative permeability

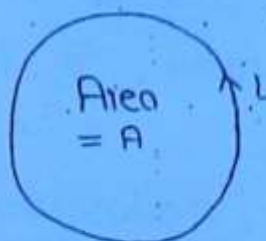
μ_0 - Permeability in free space.

(2) Magnetic dipole moment → * A current loop constitutes a mag. dipole.

* Mag. dipole moment is defined as the product of the area of loop and current through the loop.

It is the vector quantity and its direction is normal to the plane containing current loop.

(73)



$$\vec{P}_B = i \times A \hat{n}$$

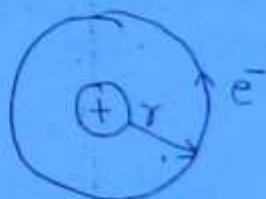
\hat{n} - unit vector along normal to the plane.

Unit - $A \cdot m^2$

Bohr - Magnetron \rightarrow Atomic unit of magnetic dipole moment is called Bohr magnetron.

Let us consider an e^- revolving around a nucleus in a circular orbit. The current through the loop is

$$i = \frac{Q}{T}$$



$$i = \frac{e}{(2\pi/\omega)}$$

$$= \frac{e\omega}{2\pi}$$

Mag. dipole moment

$$P_B = iA$$

$$= \frac{e\omega}{2\pi} \times \pi r^2$$

$$P_B = \frac{e\omega r^2}{2} \quad \text{--- (1)}$$

By bohr's hypothesis

Angular momentum

$$mvr = \frac{nh}{2\pi}$$

(74)

Where h = Planck's constant

$$= 6.623 \times 10^{-34} \text{ J-s}$$

$$m(\omega r).r = \frac{nh}{2\pi}$$

$$\omega = \frac{nh}{2\pi m r^2}$$

from eqⁿ ①

$$P_B = \frac{er^2}{2} \cdot \left(\frac{nh}{2\pi m r^2} \right)$$

$$P_B = \frac{neh}{4\pi m}$$

$$\perp M_B = \text{Bohr magneton} = \frac{eh}{4\pi m}$$

$$= \frac{1.6 \times 10^{-19} \times 6.626 \times 10^{-34}}{4 \times \pi \times 9.1 \times 10^{-31}}$$

$$\perp M_B = 9.27 \times 10^{-24} \text{ A-m}^2$$

Larmor's angular freq :-

$$\text{When } B=0 \quad \omega = \omega_0 = \frac{nh}{2\pi m r^2}$$

$$B \neq 0 \quad \omega = \omega_0 + \omega_L$$

Larmor's angular freq

$$\omega_L = \frac{eB}{2m}$$

(75)

It is defined as the change in angular freq. of orbital \vec{e} when... an external mag. field is applied.

Magnetization: — (M) It is defined as magnetic moment per unit volume.

$$M = \frac{P_B}{\text{Volume}}$$

$$M = N \mu_B$$

Where N - no. of dipole per unit vol.

unit — A/m.

The magnetic flux density inside a magnetic material under the influence of external field has two component;

* One component because of magnetisation

* Other one because of external field.

$$B = \mu_0 H + \mu_0 M \longrightarrow D = \epsilon_0 E + P$$

$$B = \mu_0 (H + M)$$

$$\cancel{\mu_0} \mu_r H = \cancel{\mu_0} (H + M)$$

$$M = (\epsilon_r - 1) H \longrightarrow P = \epsilon_0 (\epsilon_r - 1) E$$

$$M = \chi_m H \longrightarrow P = \epsilon_0 \chi_e E$$

Where χ_m — Mag. susceptibility.

Where $\chi_m = \mu_r - 1$

(26)

$$= \begin{cases} +ve. \text{ material will be attracted by mag. field.} \\ -ve \text{ material will be repelled by mag. field.} \end{cases}$$

Que:- Find the magnitude of the magnetic flux density in a material

i) The magnetization is 2.8 A/m magnetic susceptibility is $.0025$

ii) The mag. field intensity is 1300 A/m & $\mu_r = 1.006$

iii) There are $8.2 \times 10^{28} \text{ atom/m}^3$ each having a dipole moment of $3 \times 10^{-30} \text{ A-m}^2$ in the same direction & $\chi_m = 2 \times 10^{-4}$.

Solⁿ (i) $B = \mu_0 H + \mu_0 M$

$$= (4\pi \times 10^{-7} \times 1120) + (4\pi \times 10^{-7} \times 2.8)$$
$$= 1.411 \times 10^{-3} \text{ Wb/m}^2$$

$$M = 2.8 \text{ A/m} \quad N = 8.2 \times 10^{28}$$

$$\chi_m = .0025$$

$$H = 1300 \text{ A/m}$$

$$\mu_r = 1.006$$

$$M = \chi_m H$$

$$\frac{2.8}{.0025} = H = 1120 \text{ A/m}$$

(ii) $H = 1300 \text{ A/m} \quad \mu_r = 1.006$

$$B = \mu_0 \mu_r H$$

$$= 1.64 \times 10^{-3} \text{ Wb/m}^2$$

(iii) $N = 8.2 \times 10^{28} \quad p_B = 3 \times 10^{-30} \text{ A-m}^2 \quad \chi_m = 2 \times 10^{-4}$

$$\cancel{M = \chi_m H}$$

$$M = N p_B$$

$$= .0246 \text{ A/m}$$

$$B = \mu_0 \mu_r H$$

$$= \mu_0 (\chi_m + 1) \left(\frac{M}{\chi_m} \right)$$

$$= 1.54 \times 10^3 \text{ Wb/m}^2$$

(77)

* Origin of permanent magnetic dipole.

Moment in materials —

* When ever a charge particle has an angular momentum, the particle will contribute to permanent dipole moment.

* In general there are three contribution to the angular momentum of an atom.

① Orbital angular momentum of an \bar{e} →

It is due to orbital motion of \bar{e}

② Electron spin angular momentum → It is due to self spin of \bar{e} .

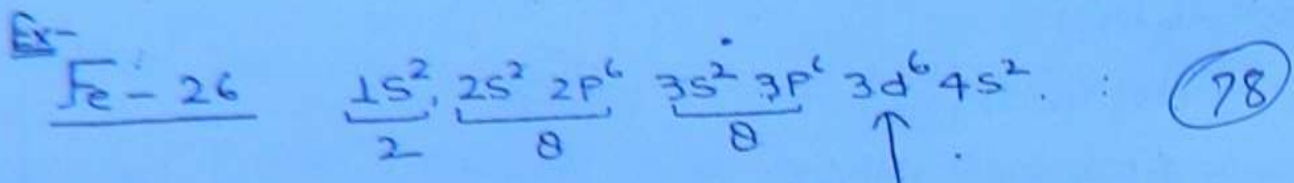
③ Nuclear spin angular momentum →

It is due to nucleous spin.

* Magnetic properties of material are only effected by electron spin dipole moment (angular momentum).

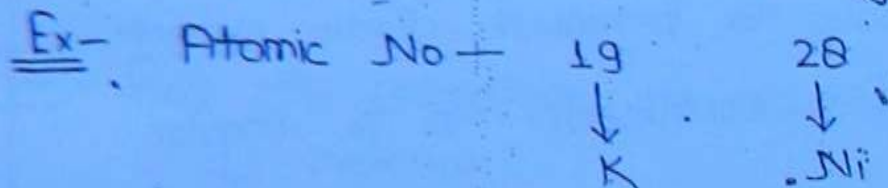
* Electron spin angular momentum → * Since \bar{e} has 0 charge, so its spin produces 0 magnetic dipole moment.

* The atoms having completely filled inner shells have 0 resultant spin dipole moment.



inner 3d state is incompletely filled.

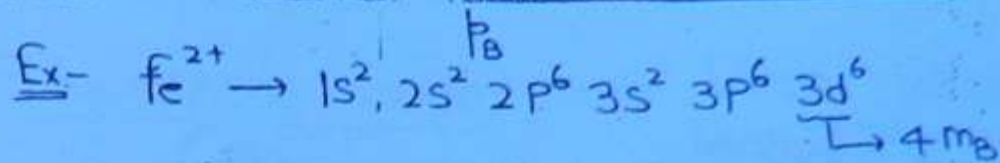
A Group of element having incompletely filled 3d state is known as transition group.



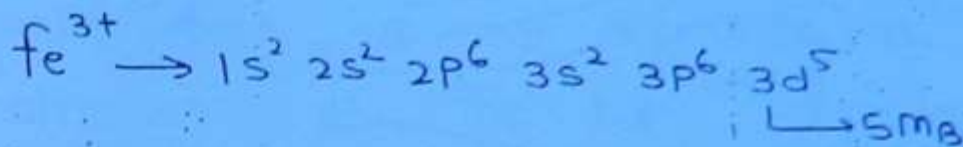
1 Bohr magneton = $\frac{eh}{4\pi m}$

= $\pm \frac{eh}{4\pi m}$ (due to opposite spins of \bar{e})

Atomic No.	element	\bar{e} in 3-d state	$\mu_B (M_B)$
20	Ca	0	0
21	Sc	1	M_B
22	Ti	2	$2M_B$
23	V	3	$3M_B$
24	Cr	4	$4M_B$
25	Mn	5	$5M_B$
26	Fe	6	$(10-6) = 4M_B$
27	Co	7	$(10-7) = 3M_B$
28	Ni	8	$(10-8) = 2M_B$
29	Cu	10	0



(79)



⇒ The magnetic moment in units of Bohr magneton of an ferrous ion in any ferrite is —

(a) 0 (b) 2

(c) 4 (d) 6

⇒ The outer most electronic configuration of a cobalt atom is



$(10 - 7) = 3$ Bohr magneton

Classification of magnetic materials →

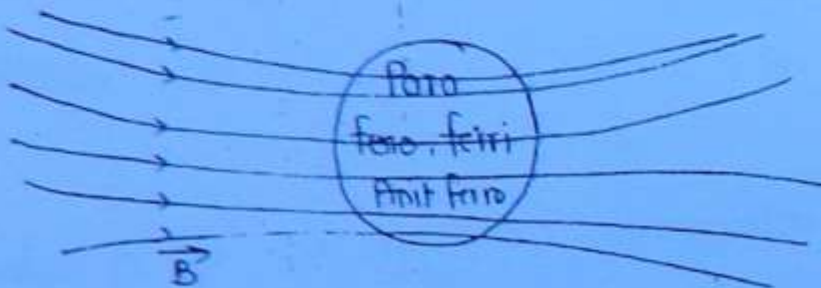
- diamagnetic material
- Paramagnetic material
- ferromagnetic
- Antiferromagnetic
- ferrimagnetic

(1) diamagnetic material → These materials have small & negative magnetic susceptibility.

* These materials are repelled by applied magnetic field.



(80)



The magnetic flux inside diamagnetic material is

$$B_i = 0$$

$$\mu_0 [H + M] = 0$$

$$M = -H$$

$$M = \chi_m H$$

$$\chi_m = -1 = \mu_r - 1$$

$$\mu_r = 0$$

The above relation $\mu_r = 0$ all the perfect diamagnetism is one of the necessary 'cond' for a material to be a super conductor.

Magnetic susceptibility of these material is independent of Temperature.

Ex- Si, Ge, diamond, NaCl, Al_2O_3 , Cu, Au (Gold) etc

○ Paramagnetic material → When these material is placed in an external (81) magnetic field, it acquires a weak magnetisation in the same direction of magnetic field.

* These materials have small positive value of magnetic susceptibility.

In Paramagnetic material permanent dipole moment of the atoms and ions has no mutual interaction. However in the presence of field the mag. moment have a tendency to turn towards the direction of applied field.

* If no. opposing force act, complete alignment of the dipole will be produced. And the specimen would acquire a very large magnetization. But thermal agitations of atoms opposes this tendency and tends to keep the dipole moment at ~~and~~ random.

This result only a partial alignment in the field direction. Therefore a weak magnetisation and small positive value of susceptibility. The effect of increase the temp. is to increase the thermal agitation & therefore decrease the susceptibility.

The magnetization is governed by a law called Curie-law.

$$M = \frac{N \mu_B^2}{KT} \cdot H$$

(82)

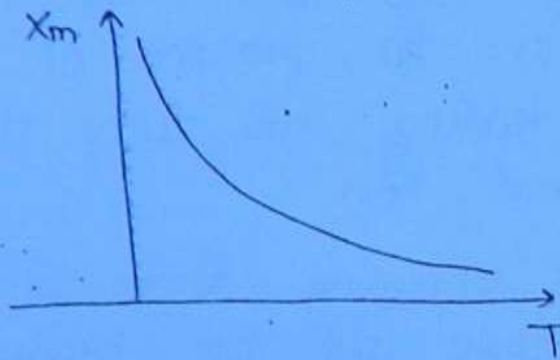
$$M = \frac{C}{T} H \rightarrow \text{Curie law.}$$

$$M = \chi_m H$$

$$\chi_m = \frac{C}{T}$$

$$C = \frac{N \mu_B^2}{K}$$

→ Curie - Constant



Some Paramagnetic material follow Curie-Weiss Law

$$M = \frac{N \mu_B^2}{KT} H_i$$

$$H_i = H + \gamma M$$

$$M = \frac{N \mu_B^2}{KT} [H + \gamma M]$$

$$M = \frac{\frac{N \mu_B^2}{KT}}{1 - \frac{N \mu_B^2}{KT} \cdot \gamma} \cdot H$$

$$M = \frac{N \mu_B^2}{1 - \frac{N \mu_B^2}{K} \cdot \gamma} H$$

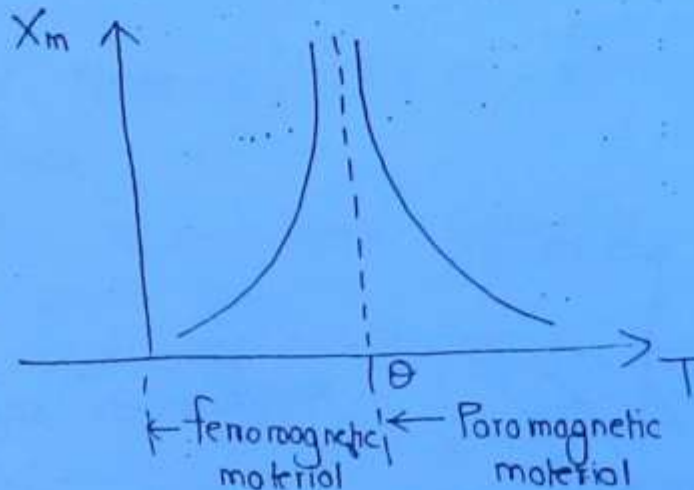
$$M = \frac{C}{T - \theta} H \quad \bigg| \quad P = \frac{CE_0}{T - \theta} E$$

(83)

Where $C = \frac{N\mu_B^2}{K}$ - Curie Const.

$$\theta = \text{Curie-temp.} = \frac{N\mu_B^2}{K} \gamma$$

$$\gamma = \text{internal field const.} = \frac{\theta}{C}$$



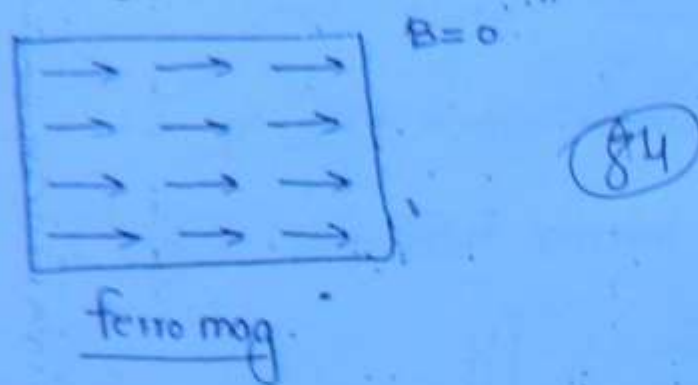
Ex- FeSO_4 , MnSO_4 , NiSO_4 , Fe_2O_3 etc

Ferromagnetic Material \rightarrow These are the material which get magnetise in

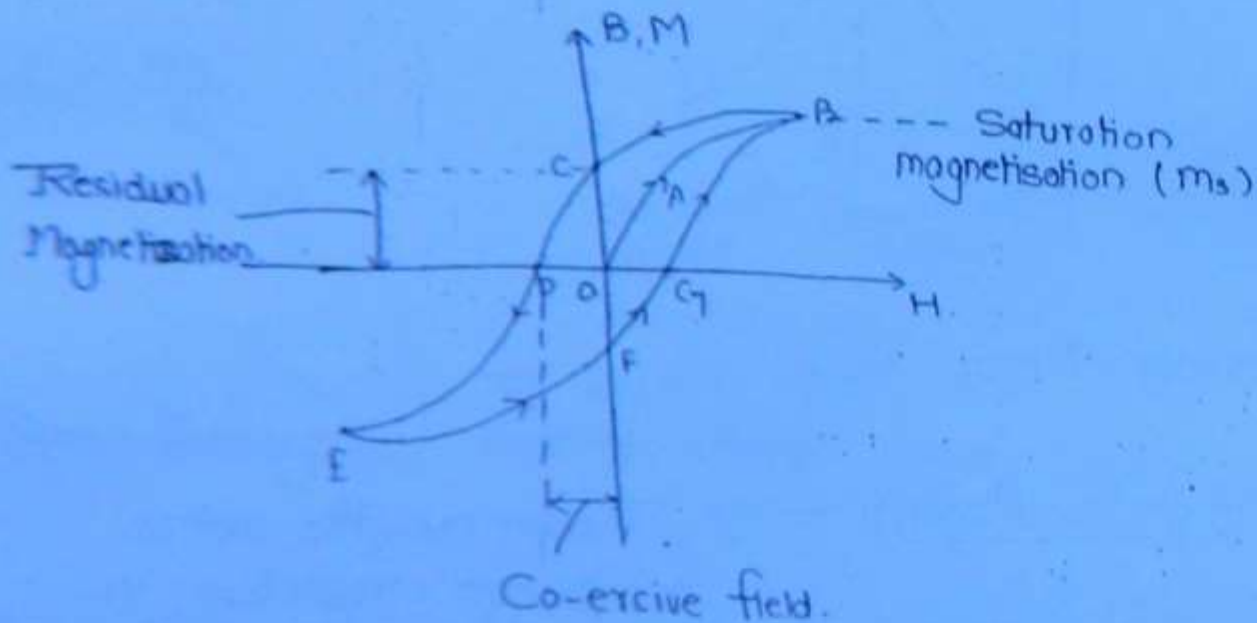
the direction of external field and remain magnetise ever after the removal of mag. field. This property of ferro mag. material is called spontaneous magnetization.

* direction of magnetization can be reverse by reversing the direction of external mag. field.

* The ferro mag. material are characterise by parallel alignment of magnetic dipole.



Hysteresis Curve →



* When a magnetic field applied to a ferro mag. material, the material follows the path OAB in the hysteresis curve.

* When the mag. curve is reduce to zero, the non zero value of magnetization is called residual magnetization.

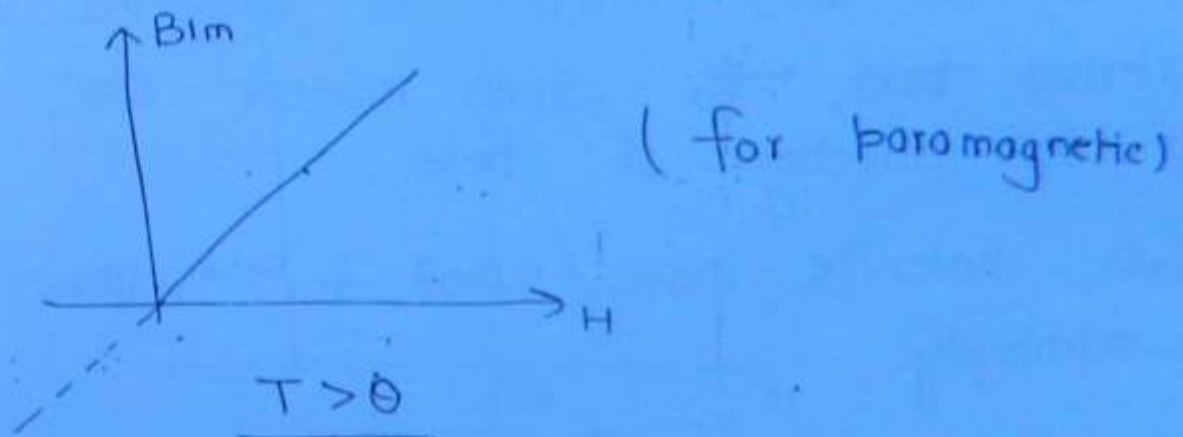
* To reduce the magnetization to zero an external

field is ^{required to} applied ~~to~~ in opposite direction known as ~~co-er~~ co-ercive field. The material never comes back to its original state once exposed to external field. (S)

The ferro magnetic material remain ferro magnetic up to a critical temp. called curie temp.

* These materials start behaving like Paramagnetic material.

* Above curie-temp hysteresis loop merges to a straight line.



Ex- Fe, Co, Ni, Gd (Gadolinium), Dy (Dysprosium) etc.

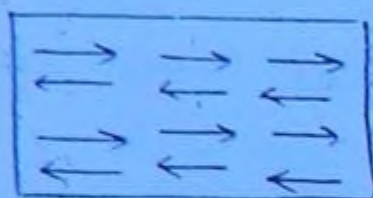
V.V. ~~not~~

Material	Curie temp ($^{\circ}\text{K}$)
Co	1404
Fe	1043
Ni	631
Gd	289

(3) Anti ferro magnetic material →

(86)

The dipole moment in these material are aligned in antiparallel direction.



Anti ferro mag $B=0$

Net magnetisation is 0 when no external field is applied, but when material is subjected to an external field, the dipole moment start aligned in the direction of field.

These materials have small + (ve) values of susceptibility.

These material are anti-ferro magnetic up to a critical temp called Neel temp.

And above this temp. these material start behaving like paramagnetic, And magnetization is governed by a law is similar to curie-weiss law, which is given by -

$$\chi_m = \frac{C}{T - (-\theta)}$$

Where θ = Neel temp
= -ve value.

$$\rightarrow \theta = - \frac{N \mu_B^2}{K} \gamma$$

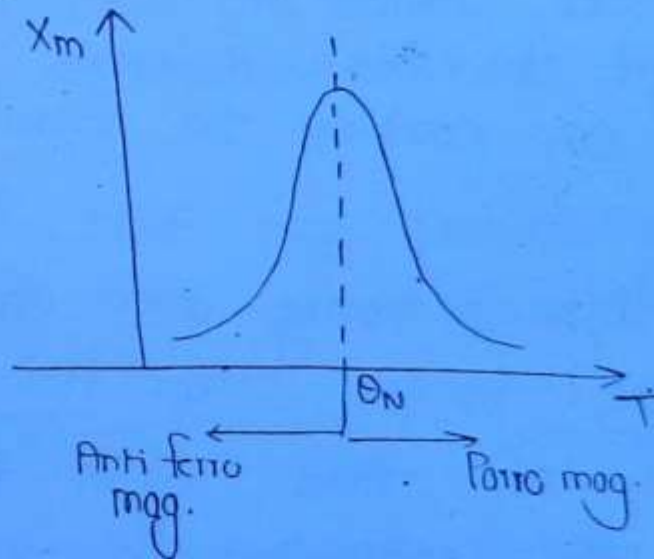
(87)

$$\theta = \frac{N \mu_B^2}{K} (-\gamma)$$

$$\rightarrow H_i = H - \gamma M$$

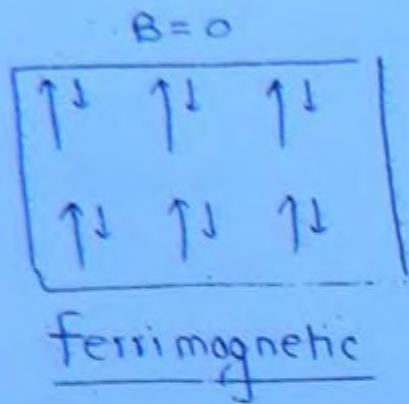
It means internal magnetisation is opposite to applied mag. field

X_m vs T



Ex - MnO_2 , MnO , FeO , CoO etc.

(4) ferri magnetic material \rightarrow In ferrimagnetic material dipole moment of adjacent atom are also aligned in opposite direction but they are not equal in strength.



88

- * These materials remain ferrimagnetic upto a critical temp. called Curie temp. and above this temp. this material starts behaving like Paramagnetic.
- * The advantage of these materials is high d.c resistivity as compared to ferromagnetic material
- * Because of this property, AT current losses in ferrite are less than ferromagnetic material and because of this reason ferrites are preferred for the construction of core of high freq. transformer.

Electrical & Magnetic characteristics of ferrite:-

- 1) High d.c resistivity
- 2) Low eddy current losses

3) High permeability

4) high dielectric constant

5) high Curie temp.



Application of ferrites: —

→ Hard

→ Soft

→ Rectangular

→ Microwave

Soft

~~Hard~~ ferrites → These are ferrites which are used for construction of core of inductors & transformer.

* These materials have high permeability, low coercive force and low eddy current losses.

Ex- Mn & Zn ferrites.

~~mp~~ Ni-Zn ferrites → (used in audio & TV transformer)

Hard ferrites : — These are the ferrites which are used for construction of permanent magnet.

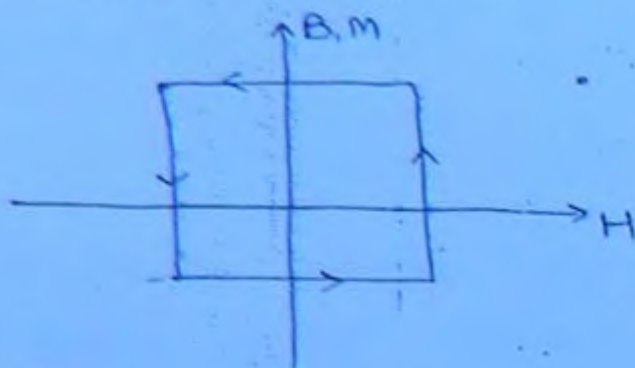
* These materials have high permeability

* high coercive force

* high resistivity

Ex- Ba & Sr ferrites.

31. Rectangular ferrites → These ferrites are having rectangular shape of hysteresis curve.



(90)

These ferrites are used as the core of magnetic memories.

Ex- Mn-Mg ferrites.
Ni-Li "
Mn-Cu "

Micro wave ferrites → These ferrites is used at microwave frequency

* At these freq. the electro magnetic wave interact with the spin magnetic moment of \bar{e} because of this the plane of polarization of electromagnetic field gets rotated by some angle. When the wave passes through the material this phenomenon is called Faraday rotation.

These ferrites is used in micro wave devices

x- Gyrotors, Circulators & Isolators etc.

x. of microwave ferrites —
Mn-ferrites

② Co - ferrites

③ Ni - ferrites

(91)

④ Garnets (YIG - Yttrium-iron-garnet)

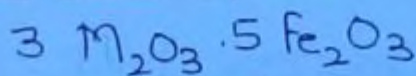
→ used in magnetic bubble memory

ferrites from magnetite → $M_0 Fe_2 O_3$

Where M - bivalent element

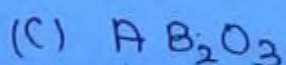
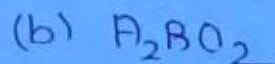
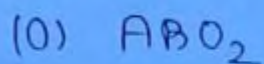
Ex:- Cu, Zn, Co, Ni etc

ferrites from Garnets:-



These are called "rare earth ferrites".

Ques:- ferrites can be considered as mixed oxide of metals A & B having inverse spinel structure
their formula can be written as



Magnetic Anisotropy:- In single crystal material such as iron the magnetic properties of material depend on the direction in which they are measured. This property of magnetic material is called mag. anisotropy.

The ~~ore~~ three methods to induce anisotropy

→ Cold Working

→ Magnetic Annealing

→ Magnetic Quenching

(92)

Cold Working — Such as cold rolling induces the uniaxial magnetic anisotropy in the direction of rolling.

Magnetic Annealing — In this process heat treatment is done in the presence of magnetic field in order to induce magnetic anisotropy.

Magnetic Quenching — In this process the material is cooled down to Curie temp. in the presence of magnetic field.

The magnetic quenching induces the magnetic anisotropy either in the direction of field or perpendicular to the field.

Magnetostriction : — When a material (magnetic material) is magnetised changes in dimension are generally observed, this property of magnetic material is called magnetostriction.

c

c There are three type of magnetostriction.

c → Longitudinal

c → Transverse

c → Volume

(13)

c 1) Longitudinal → When change in the dimension is
c In the direction of applied field.

c (2) Transverse → When change in the dimension is
c perpendicular to applied field.

c (3) Volume → When change in the dimension is
c ⊥ as well as parallel to applied
c field.

c Some important point →

c 1) Magnetostriction is responsible for humming noise
c In the core of T/F.

c 2) Magnetostriction is caused by rotation of domain
c of ferromagnetic material under the influence of
c applied mag. field.

c 3) (+ve) magnetostriction → material expands with
c increase in the strength
c of applied mag. field and it contracts when
c strength decreases.

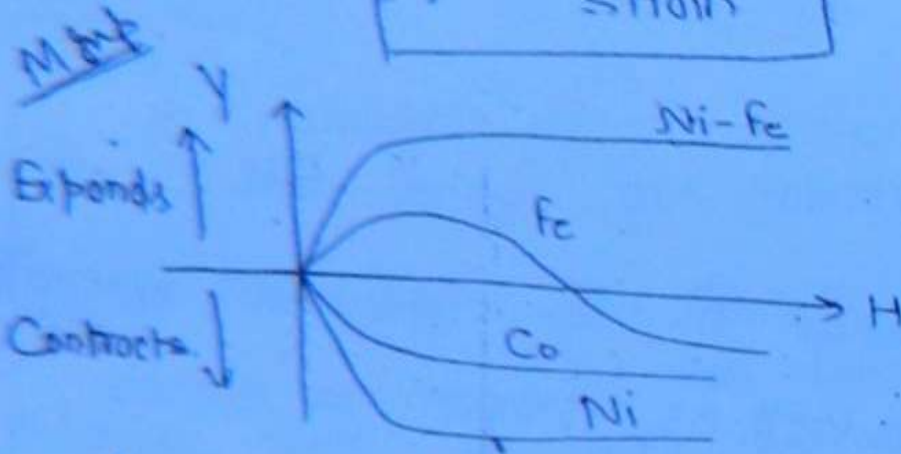
c Ex- Ni-Iron alloys.

Negative magnetostriction → material expand with decrease in the strength of applied magnetic field and its contracts with increase in the strength.

Fe, Co, Ni

$$\gamma = \frac{\text{stress}}{\text{strain}}$$

(94)



Application of magnetostriction →

Under water sound detection

Generation of super sonic sound

Generation of high freq. oscillation.

Villari Effect →

It is converse of magnetostriction

The longitudinal deformation leads to change in magnetic permeability of material in the direction of applied stress

Case-1 Material with (+ve) γ (Young modulus) (strain)

$\rightarrow \mu \uparrow$ with expansion.
 $\mu \downarrow$ " contraction.

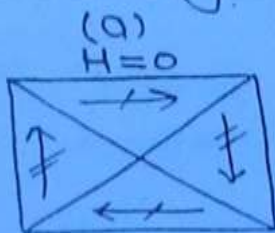
(93)

Ex- Ni-Fe alloys

Case-2 Material with (-ve) γ strain

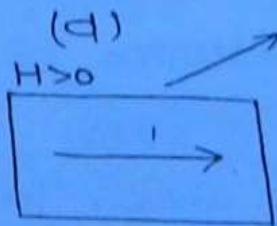
$\rightarrow \mu \uparrow$ with contraction
 $\rightarrow \mu \downarrow$ " expansion.

ferromagnetic domain \rightarrow (Conventional).

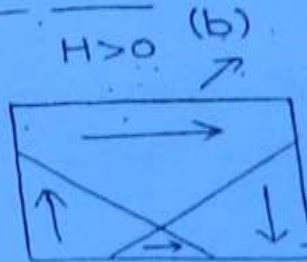


(Multi domain state)

(Net magnetization is zero)

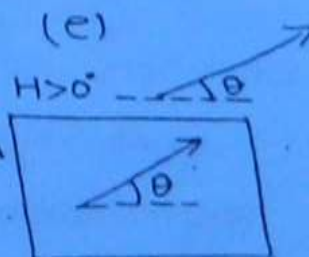
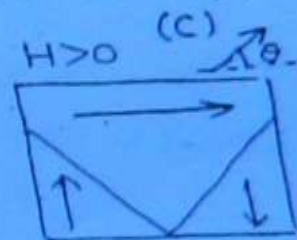


Single domain formation



growth of domain

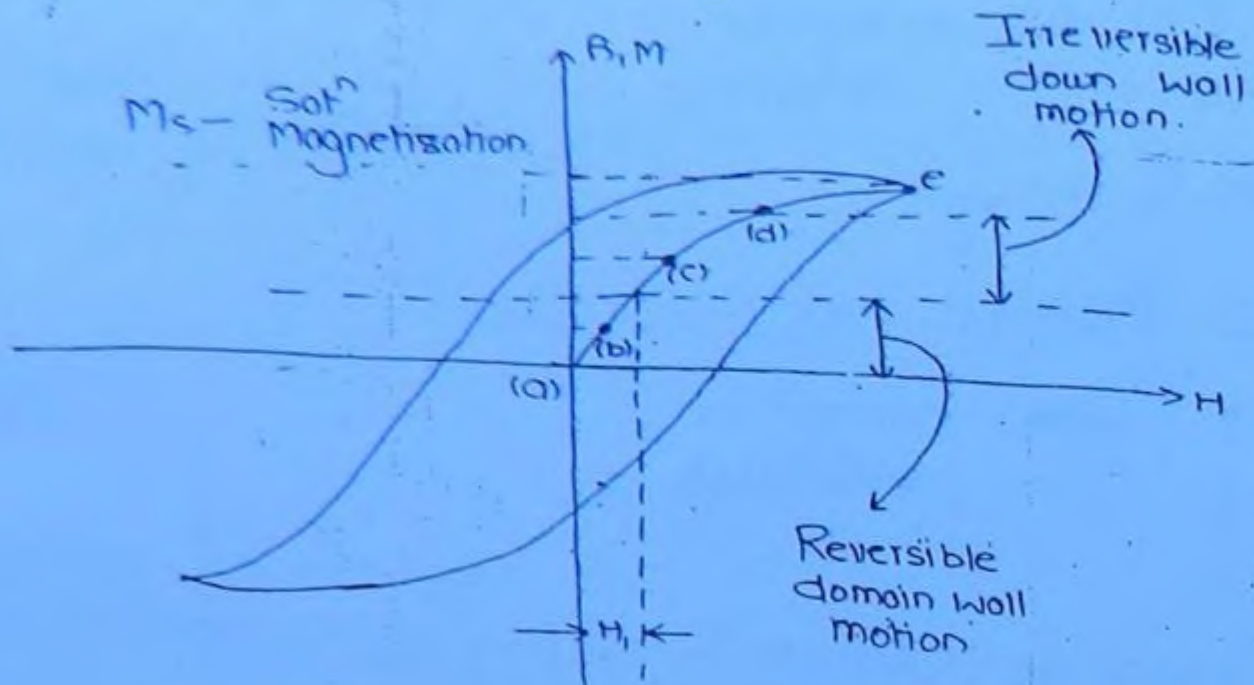
unfavorable domain



Rotation of domain in the dirⁿ of field.

Hysteresis Curve →

(96)



$H < H_c$ → On removal of field, displaced domain walls once again take their positions.

In ferromagnetic material (Indemagnetize state) ~~for~~ several domain are present. and each domain is spontaneously magnetize (having their own saturation magnetization), but the direction of magnetization of the various domain are such that as a whole specimen there is zero magnetization. as shown in fig. (D),

When a mag. field is imposed on the material domains are lined up with the field growth at the expense of unaligned domain. (Conversion, from

multi domain state to single domain) as shown in fig. (b) & (c). (9)

This process continues until the most favorably domain remains in material as shown in fig (d)

When domain growth completed, A further increase in mag. field causes domain to rotate and aligned parallel to mag. field as shown in fig (e).

At this instant material reaches saturation magnetization and no further increase will take place on increasing the strength of mag. field.

Que:- During the process of magnetization of ferro magnetic material, the magnetic domain

- (a) Only expand
- (b) Neither rotate nor expand
- (c) Rotate first and then expand
- ☒ (d) Expand first and then rotate

Que:- Paramagnetic susceptibility of material

- (a) Increase linearly with temp
- (b) decrease " " "
- ☒ (c) increase " " " $1/T \rightarrow \chi_m = \frac{C}{T}$
- (d) decrease " " " $1/T$

Que:- Consider the following statement about ~~die~~ diamagnetic material & dia magnetism.

(98)

- (a) ~~The~~ material have negative magg susceptibility.
- (b) At very low temp diamag. material converted into Paramagnetic

Que:- Which of the following are properties of ferromag. material:

- (a) Permanent magnetism
- (b) Atomic moment in individual domains are aligned neither parallel to nor perpendicular to one another below curie temp
- (c) Each domain is magnetically saturated
- (d) Above Curie - temp domain disrupt (disordered)

Exchange interaction Energy : — * The parallel alignment of magnetic dipoles of iron, Co, Ni. is due to creation of energy known as exchange interaction energy

It is function of the ratio of atomic diameter to 3-d orbital diameter.

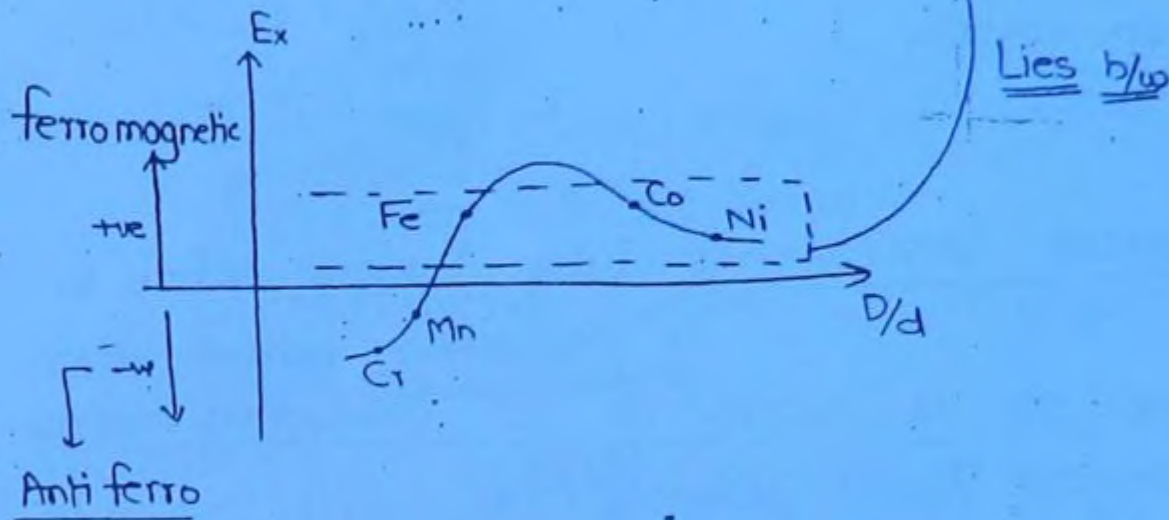
$$Ex \propto \frac{D}{d}$$

→ atomic diameter

→ 3d orbital diameter.

For parallel alignment occur the ratio must be in the range of (1.4 - 2.7) ←

(99)



Comparison between magnetic materials :-

Materials	χ_m	' χ_m ' vs 'T'	Alignment of dipoles	Examples
Diamagnetic	Small & -ve	χ_m is independent of temp.	no dipoles	Si, Ge, Cu, Au, diamond, NaCl
Paramagnetic	(+ve) & small ($\approx 10^{-3}$)	$\chi_m = \frac{C}{T}$ Curie law Or $\chi_m = \frac{C}{T - \theta}$ Curie-Weiss law	random	MnSO ₄ , NiSO ₄ , FeSO ₄ , Fe ₂ O ₃
ferromagnetic	(+ve) & Very large	$\chi_m \rightarrow \infty$	↑↑↑↑↑	Fe, Co, Ni
Anti-ferromagnetic	(+ve) & small	$\chi_m \rightarrow \chi_m \text{ sat}^n$	↑↓↑↓↑↓	MnO, MnO ₂ , FeO
ferrimagnetic	(+ve) & large	$\chi_m \rightarrow \infty$	↑↓↑↓↑↓↑↓	ferrites, Garnet

Core losses →

1. Eddy Current Losses
2. Hysteresis losses

(100)

(1) Eddy Current Losses → Eddy current refers to a circulating current which are introduced in a section of a conducting material when it is subjected to an a.c. field.

Eddy current losses are given by

$$\left(\frac{\text{Watt}}{\text{m}^3}\right) P_{\text{eddy}} = \frac{\pi B^2 f^2 t^2}{\rho \cdot \beta}$$

Where B - mag. flux density
f - freq. of applied ac field.

t - thickness

ρ - resistivity

β - constant

$f \uparrow \rightarrow P_{\text{eddy}} \uparrow$

$\rho \uparrow \rightarrow P_{\text{eddy}} \downarrow$

ferites are

To reduce eddy current losses are higher freq.
iron cores are laminated or Si-steel is used.
(higher d.c resistivity.)

Si-Steel \rightarrow is a ferrites.

(2) Hysteresis losses :—

$$P_{hy} (\text{Watt/m}^3) = \eta B^n f$$

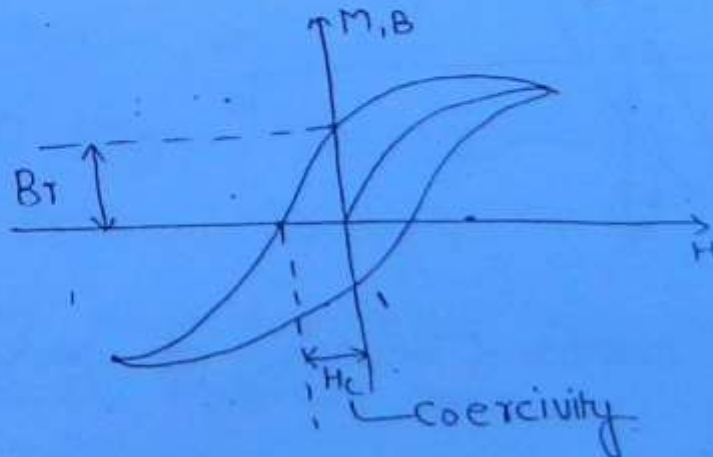
(10)

Where — B — mag. flux density
 f — freq. of ac field.
 η — material Constant
 n — an exponent

$P_{hy} \propto \text{Area of hysteresis loop}$

\rightarrow Soft mag. material and soft ferrites has low co-ercive force and less area of hysteresis loop. So they are used in high freq. electromagnetic devices.

Retentivity \rightarrow Residual flux density is called retentivity.



Coercivity \rightarrow max^m value which a coercive field can attain.

(102)

Soft & hard magnetic material

Soft magnetic material

\rightarrow These materials are easy to magnetise & demagnetise

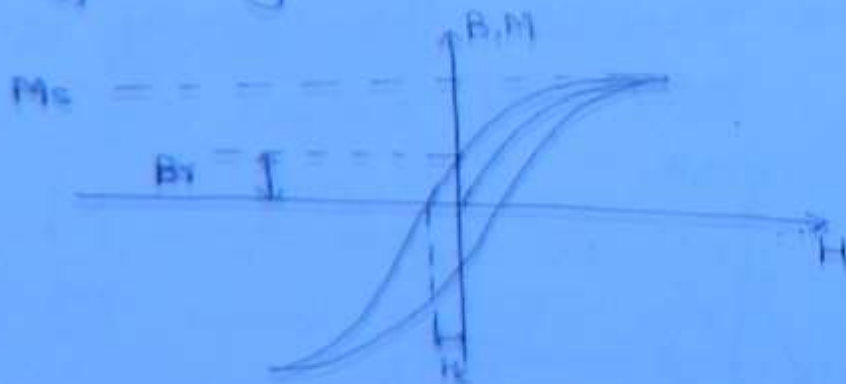
\rightarrow These materials favour rapid switching of magnetization
(it means high ω freq.)

\rightarrow These materials have low retentivity

\rightarrow Low coercivity

\rightarrow high permeability

\rightarrow high magnetic saturation.



\rightarrow Low hysteresis losses (because of lesser area of hysteresis loop)

\rightarrow These materials are used for transformer & inductance core, to minimize energy dissipation (reduction in hysteresis)

→ desirable for electromagnets

(93)

Ex: ① Si-Steel / Soft-Iron / Fe-Si alloy :- It is used upto power

freq. (50 to 60 Hz)

→ It is used in power transformer.

→ When 5% Si is added it increases max^m permeability d.c resistivity and reduces the area of hysteresis loop (low hysteresis losses)

→ Low eddy current losses.

② Fe-Ni alloy :-

(a) 36% Ni (In-var) → Used for high freq applications such as used as high speed relay & transformer.

(b) 50% Ni - Used for magnetic memory

(c) 77% Ni - Used for precision voltage & current transformer

(d) Permalloy - 45% Ni

(e) Super-alloy - 79% Ni

(f) Mu-metal - 75% Ni

Alloys (d), (e) & (f) have high permeability and less area of hysteresis loop.

Hard magnetic materials → These materials are also called permanent magnet material

→ These material retain their magnetisation and difficult to demagnetize.

→ These materials have high... retentivity

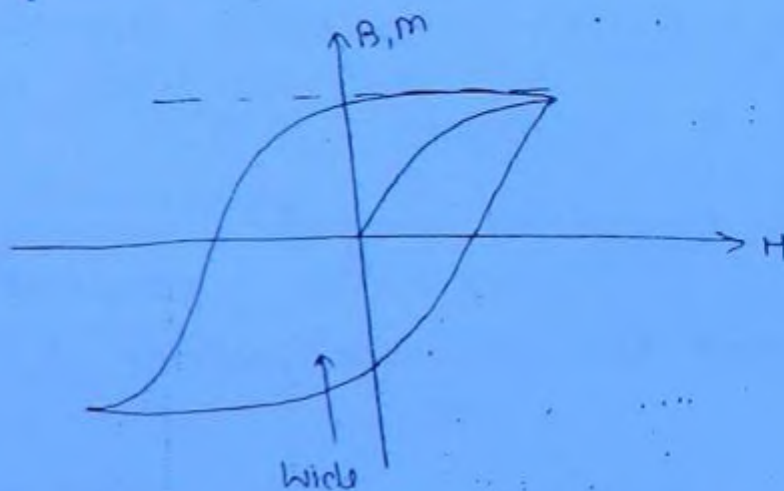
→ high Coercivity

→ high permeability

→ high magnetic saturation

→ high Curie point Or temp.

→



→ high hysteresis losses (because of large area of B-H Curve).

Ex- (a) Carbon-steel — Used as magnet for latching relays or compass needle.

(b) Tungsten-steel : — Used as magnets in d.c motor.

(3) Alnico (Al, Ni, Co) — Their magnetic properties are very stable with ~~time~~ temp. 105

(4) Ba-ferrite

(5) Remolloy

(6) Cunite (Cu, Ni, Fe)

Que:- For permanent magnetic material.

- (a) the area of hysteresis loop should be small
- (b) The initial relative permeability should be large
- ~~(c)~~ The residual induction & coercive field should large
- (d) " " " " " " small

Que:- Consider the following statement

In a T/F the core material should be low.

~~(a)~~ Coercivity

~~(b)~~ retentivity

(c) permeability

Que:- Magnetic Cores required for radio freq. application should have.

	hyst loop	Eddy Curr loss
(a)	high	h
(b)	L	h
(c)	L	L
(d)	h	L

(106)

~~**~~ For radio freq. the freq. will be high.
We use soft material so the B-H curve will be less
So the Eddy + hyst loss will be low.
How can eddy current loss in the core of T/F
be minimize

- ~~Let~~ by \uparrow the resistivity of core
- ~~Let~~ by using Laminated sheets with insulator coating
- (c) by using highly insulating non-magnetic material for
- (d) by ~~the~~ using the Paramagnetic material as the core

Which material is used for making Permanent magnet

- (a) Si-Steel
- (b) Permalloy
- ~~(c) Carbon-steel~~
- (d) None of these

The hysteresis loop for material of the core of Transformer should be

- (a) Short + wide
- (b) Short + narrow
- ~~(c) tall + narrow~~
high mag sat high mag permeability
- (d) tall + wide

Math

Match list I + List-II

(107)

List-I

List-II

1. Permanent magnet → Ferrites
2. high freq. application in (MHz) range → Garnets
3. Electromagnets → Hard mag material
4. Very high freq (GHz) → Soft mag. "

(a) 1 2 4 3

(b) 2 1 3 4

(c) 3

(d) 1 2 3 4

Conducting + Insulating Materials

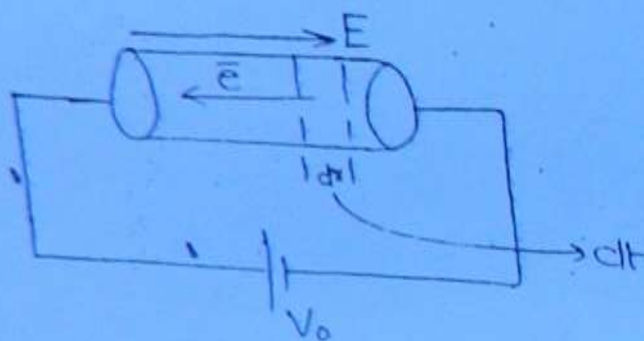
Conductors →

(108)

Ohm's Law (point form) -

$$\boxed{J = \sigma E}$$

Proof: →



Under the influence of electric field the motion of electron in conducting material have two component

- (1) random motion of \vec{v}_d which depend on T .
- (2) directed motion of \vec{v}_d " " applied external field

The force experienced by \vec{v}_d under the influence of external field is given by.

$$m \frac{d^2 x}{dt^2} = -eE$$

$$\frac{d^2 x}{dt^2} = -\frac{eE}{m}$$

$$\frac{dx}{dt} = -\frac{eE}{m}t + V_{\text{random}}$$

(189)

→ drift Velocity of \bar{e} ~~which~~ is defined for avg collision time. which is the avg. time b/w the two successive collision of \bar{e} .

→ Over the avg. collision time random velocity of \bar{e} is 0.

$$V_d = -\frac{eE}{m}\tau + 0$$

Where τ - avg. collision time

$$\tau \propto \frac{1}{\sqrt{T}}$$

Now,

$$V_d = -\frac{eE}{m}\tau$$

$$V_d = \frac{eE}{m}\tau$$

$$= \mu E$$

$$\mu = \frac{e\tau}{m}$$

J - Current density

$$= \rho \cdot V_d$$

→ charge density (C/m^3)

$$= n_e e V_d$$

$$= n_e e \frac{eE}{m}\tau$$

$$J = \frac{ne^2\tau}{m} \cdot E$$

$$J = \sigma E$$

σ - Conductivity

$$= \frac{ne^2\tau}{m}$$

Effect of Temp. on Conductivity →

1/0

Conductor -

$$\sigma = \frac{ne^2\tau}{m}$$

$$\downarrow \sigma \propto \frac{n}{\sqrt{T}} \uparrow$$

With increase in temp there is no appreciable increase in n as conductor have already large no. of e^- in their conduction band. So overall conductivity decreases with increase temp.

Semi Conductor →

$$\sigma \propto \frac{n}{\sqrt{T}}$$

$$n_i^2 = A_0 T^3 e^{-E_{g0}/KT}$$

$$n_i = n = A_0^{1/2} T^{3/2} e^{-E_{g0}/2KT}$$

$$\frac{n}{\sqrt{T}} = A_0^{1/2} T e^{-E_{g0}/2KT}$$

Since $\sigma \propto \frac{n}{\sqrt{T}}$

$$\sigma \propto T e^{-E_{g0}/2KT}$$

$$\uparrow \uparrow \sigma \propto \frac{T \downarrow}{\downarrow e^{E_{g0}/2KT}}$$

Mean free path (λ) :— It is define as the avg. distance travelled by e^- before collision takes place

$$\lambda = v_d \cdot \tau$$

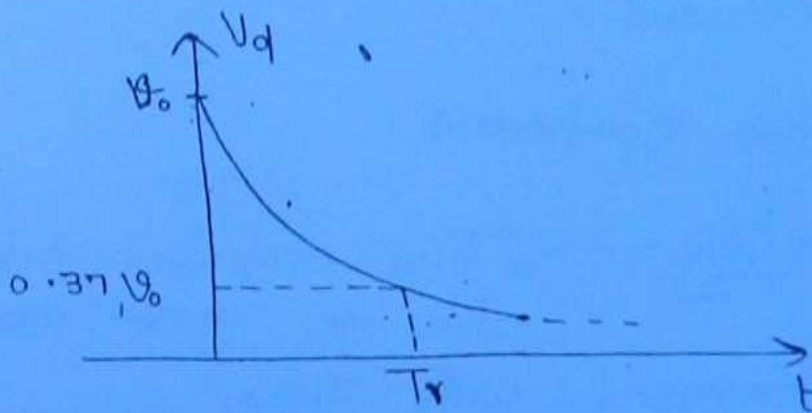
↑
drift
Velocity

Avg
Collision time.

(111)

Relaxation time : — It is define as the time required at which the drift velocity of \bar{e} reduces 37% of its value after the removal of electric field.

→ for isotropic material the relaxation time and the avg collision time are equal.



22/02

Factors affecting resistivity of metals →

(1) Temperature —

$$\rho_2 = \rho_1 [1 + \alpha (T_2 - T_1)]$$

$$T \uparrow \rightarrow \rho \uparrow$$

Where α - Temp. coefficient of resistivity

$\alpha = +ve$ (for metal)

ρ_1 = resistivity of Temp T_1
 ρ_2 - resistivity of Temp T_2

(112)

21. Alloying \rightarrow If an alloy is found by mixing two metal then the total resistivity will be greater than individual resistivity of metal.

$$\rho_{\text{alloy}} = \rho_{\text{thermal}} + \rho_{\text{residual}}$$

\rightarrow Matthiessen's Rule

Where

ρ_{th} - thermal comp of resistivity

ρ_{residual} - Residual " " "

Resistivity has two component.

\rightarrow Thermal Resistivity \rightarrow * This component arises due to lattice vibration in material which increases with Temp.

* This can be decrease to zero, by reducing the temp T_2 zero (0°K).

Residual \rightarrow * This comp. arises due to impurity & defect present in the material.

* This is independent of Temp.

* Resistivity above temp. known as Debye temp, increases linearly with increasing Temp.

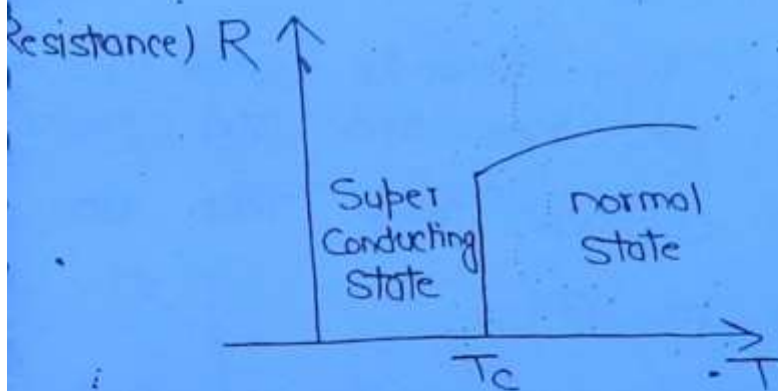
Super Conductors →

(1/13)

Super Conductivity → A state of material in which it has zero resistivity is called super conductivity.

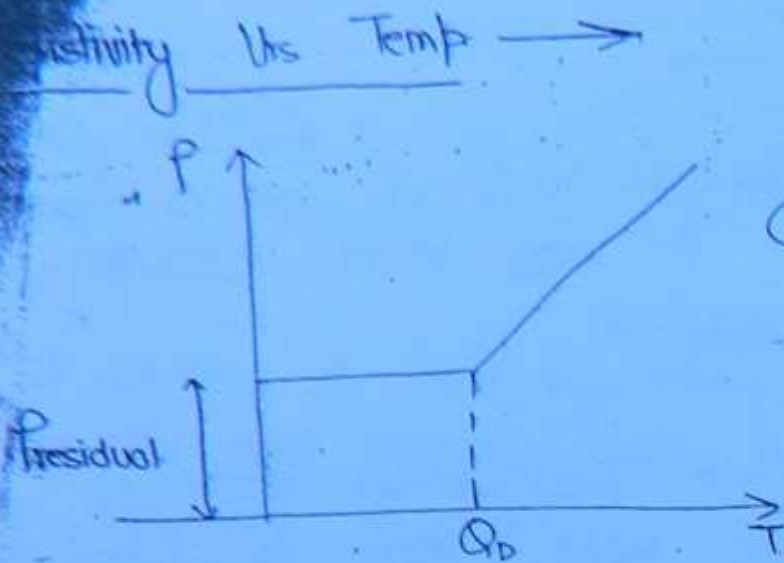
Transition Temp (T_c) → The critical temp at which there is change of state from normal to super conducting and vice-versa is known as transition temp.

R. Vs Temp →



Super Conductor → The material whose resistivity become very small or zero below the critical temp. of transition temp. are known as super conductor.

Empirical Criteria → Materials having no. of valance \approx electron (Z) from 2 to 8 generally show super conductivity.

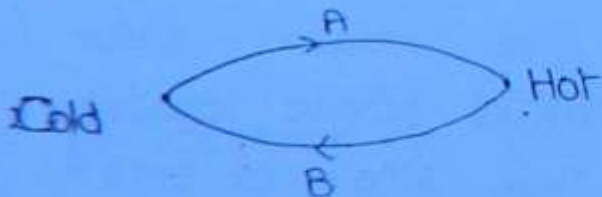


Thermo electric Effect \rightarrow

\rightarrow Seebeck effect

\rightarrow Peltier effect

Seebeck Effect \rightarrow When two dissimilar atoms are joined at their ends and junctions are maintained at different temp. then an emf exists across the junction.



Peltier Effect \rightarrow An electric current which flows through a rod consisting of two dissimilar metals causes a decrease in temp. at one end and an increase in temp. at the other end.

* It is converse of Seebeck effect.

Condition for super Conductivity →

Resistivity should be zero

$\mu_r = 0$ (perfect diamagnetism).

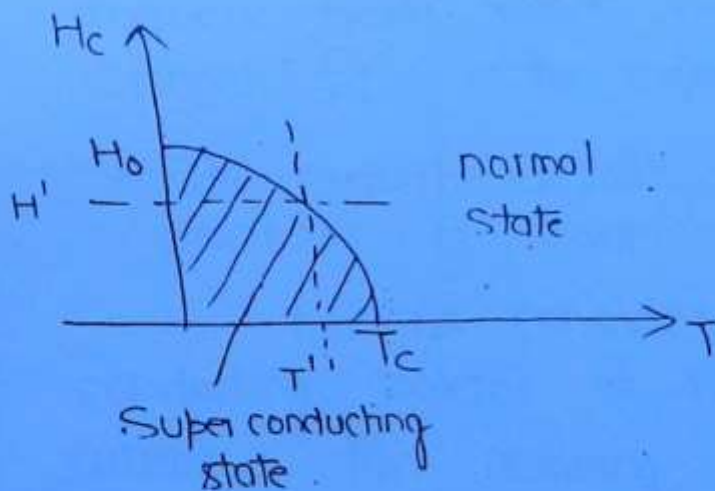
(115)

Critical field (H_c): — It is the minimum field required at a given temp to destroy super conductivity. It's value is given by —

$$H_c = H_0 \left[1 - \left(\frac{T}{T_c} \right)^2 \right]$$

Where

- H_0 — Critical field at $0^\circ K$
- H_c — Critical field at T
- T_c — Transition or critical temp.



→ Transition from the super conducting state to normal state & vice-versa is reversible.

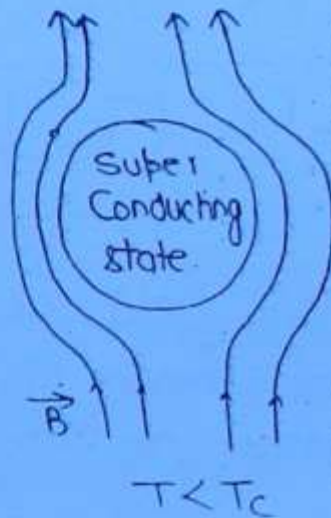
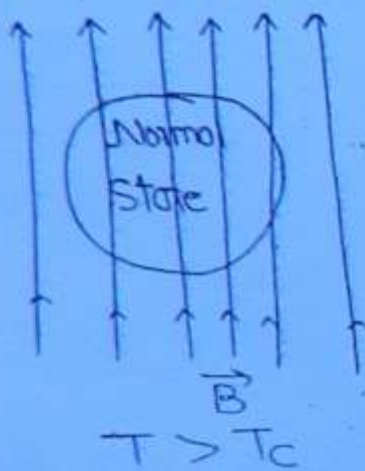
→ Transition temp. can be reduce by the application of mag. field

Transition Temp. \rightarrow

(1/6)

* Transition temp. shows max^m value for $z=3, 5 \text{ \& } 7$

Meissner's Effect \rightarrow The repulsion of magnetic flux from the interior of a piece of superconducting material, as the material undergoes to the transition to the superconducting phase is known as Meissner's effect.



In super conductor

$$B=0$$

$$\mu_0 (H + M) = 0$$

$$\boxed{M = -H}$$

$$= \chi_m H$$

$$\rightarrow \chi_m = -1$$

$$\chi_m = \mu_r - 1 = -1$$

$$\boxed{\mu_r = 0}$$

perfect diamagnetism.

Que:- The critical field for Niobium is 1×10^5 A/m at 8K and 2×10^5 A/m at 0K. Calculate critical temp. of material.

(117)

$$H_c = H_0 \left[1 - \left(\frac{T}{T_c} \right)^2 \right]$$

$$10^5 = 2 \times 10^5 \left[1 - \left(\frac{8}{T_c} \right)^2 \right]$$

$$\frac{1}{2} = 1 - \left(\frac{8}{T_c} \right)^2$$

$$\frac{64}{T_c^2} = \frac{1}{2}$$

$$T_c^2 = 128$$

$$T_c = 11.31 \text{ K}$$

Silsbee Rule \rightarrow If a superconducting material causes a current such that magnetic field which it produces is equal to critical field, the superconductivity disappears.

\rightarrow The current density at which the superconductivity disappears is known as critical current density.

Let us consider a long wire of superconducting material of radius R having a centre current i then according to Ampere's Law.

$$\oint H \cdot d\ell = i$$

$$H \cdot 2\pi R = i \dots \dots (1)$$

$$H = \frac{i}{2\pi R}$$

$$H_c = \frac{J_c}{2\pi R}$$

Critical Current.

(118)

Critical field

Critical Current density $\rightarrow (J_c)$

$$J_c = \frac{I_c}{A}$$

$$J_c = \frac{H_c \times 2\pi R}{\pi R^2}$$

$$J_c = \frac{2H_c}{R}$$

\rightarrow This rule prevents the use of super conductor as coils for the production of strong mag. field.

\rightarrow The field require to destroy the super conductivity need not be an external field it may be internal as well

Types of super Conductor :-

- \rightarrow Type-1
- \rightarrow Type-2

Type-1 Super Conductor

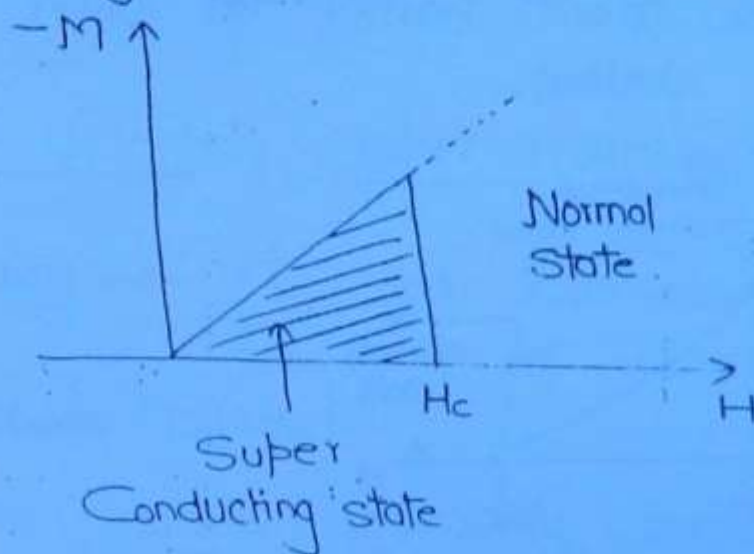
They are also called soft Super cond.

→ Their critical field & transition temp are low.

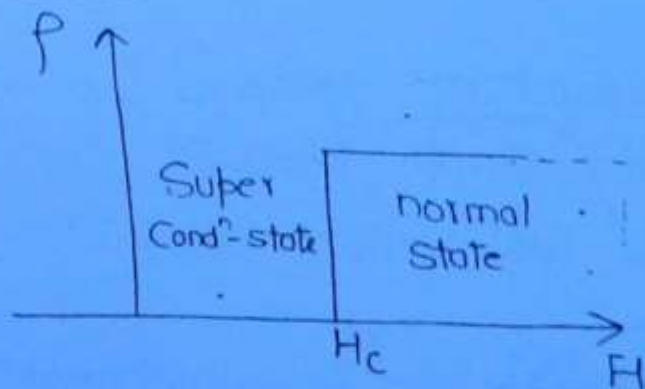
→ They exhibit complete Meissner's & Silsbee rule

→ The change of state from normal to super conducting and vice versa is abrupt

(1/9)



'f' Vrs 'H' →



Ex:- Zn, Pb, Hg, Al, In etc.

Type-2 Super Conductor → They are also called
Hard super conductor

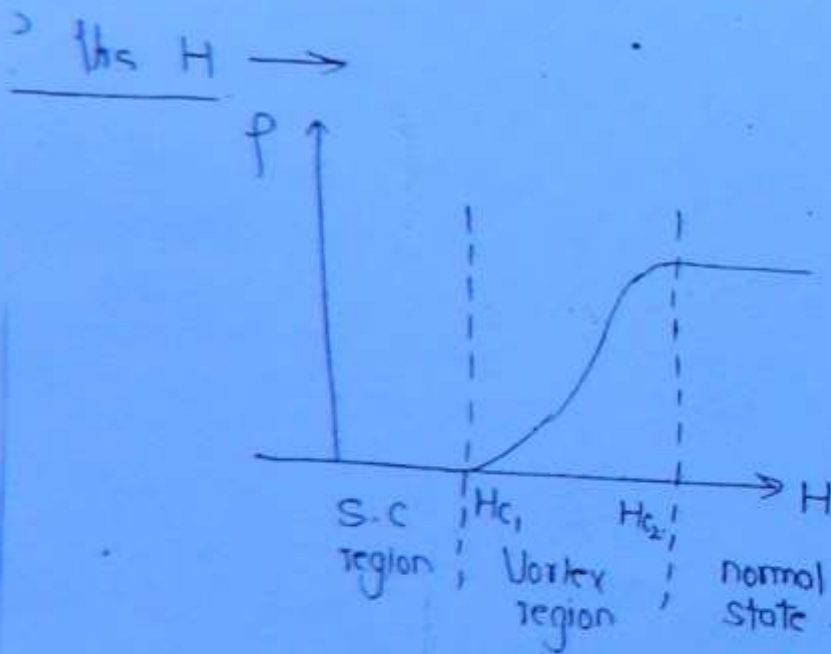
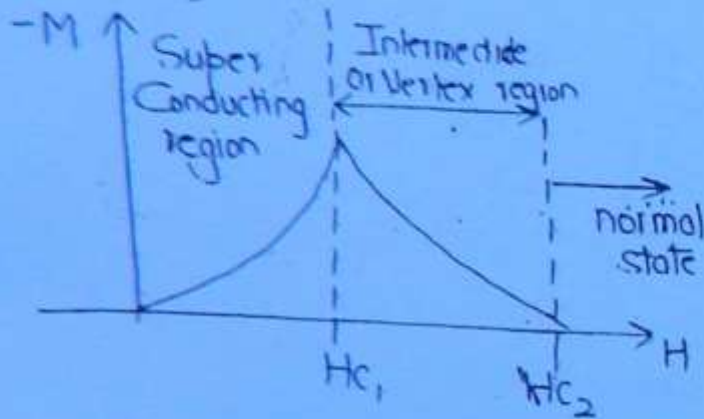
or non-ideal Super conductor

They exhibit incomplete meissner's effect & Silsbee rule

(120)

There critical field & transition temp are high

The change of state from normal to super cond. & vice versa is gradual.



These super conductor exhibit incomplete meissner's effect in Vortex region.

eg - Nb_3Al , $NbTi$ etc.

● Application —

- Magnets for nuclear fusion. (121)
- Magnetic resonance Imaging (MRI)
- Generators & Motors
- Switching elements like "Cryotrons"

● Factors affecting super conductivity & transition temp

1. frequency → S. Cond. decrease with increase freq. it is observed upto radio freq, (above 10 MHz)

Above 10 MHz resistivity increases at infrared freq. (10^{13} Hz) the resistivity is same as normal state

2. Entropy → Entropy increase on going from S. Cond state to normal state. it means S. Cond. have low entropy.

3. Thermal Conductivity → It decreases on going from ~~S. Cond~~ normal state to super conducting state.

4. Isotope Mass (m) →

$$T_c \propto \frac{1}{\sqrt{m}}$$

● Eg:- Hg (Mercury)

$$M \rightarrow 19.95 - 203.4 \text{ AMU}$$

$$T_c \rightarrow 4.185 \text{ K} - 4.16 \text{ K}$$

$$\approx \underline{\underline{4.1 \text{ K}}}$$

(122)

2) Mechanical stress or Pressure — Transition temp of S. Cond material

varies with applied mech stress or Pressure.
or Ex. there are some metal Cs (Cesium).
that become S. Cond only if large pressure is
applied to them.

Low resistivity Conducting material \rightarrow Silver has
Low resistivity
than Cu, but it is very costly, which restricts
its use for commercial purpose.

Al is cheaper than Cu, so it is often used
as a Cu substitute in electrical Power system.

Brass — Alloy of Zn-Cu

Properties of brass — high tensile strength but lower
conductivity than Cu.

Good corrosion resistant

Used in resistor, Lamp holder and plug point

Bronze \rightarrow Alloy of Cu, Tin, Al, Ni & Si.

\rightarrow Superior mech. property and corrosion resistance than ~~gross~~ brass. (123)

Phosphor bronze — Used in current carrying spring and brush holders

Silicon bronze — Wires & telephone parts

Solders

\rightarrow Solder is an alloy, which is used to joint two or more pieces of metal.

\rightarrow The melting point of ~~the~~ solder lower than the material to be join.

Types \rightarrow

① Soft Solder \rightarrow ($T < 400^\circ\text{C}$)

Alloy of Tin & lead.

② Hard Solder \rightarrow ($T > 400^\circ\text{C}$)

Alloy of Cu-Zn

\rightarrow Brazing Solder
 \rightarrow Silver "

High resistivity Conducting materials :-

(124)

Comparison between high resistivity Conducting materials

Material	Composition	ρ at 20°C ($\Omega \cdot m$)	operating temp	Application
Nichrome	Ni + Cr + Mn + Fe	100×10^{-8}	upto 1100°C	Heating element in Soldering iron furnaces
Constantan	Cu + Ni	52×10^{-8}	upto 500°C	Wire wound resistors, Rheostats, strain gauge
Manganin	Mn + Ni + Cu	48×10^{-8}	$\approx 60^\circ C$	Precision instruments bridge potentiometer
Tungsten high resistivity	metal	5.51×10^{-8}	upto 3300°C	Heating filaments such as bulbs, CRTs

Carbon →

Natural source of C is diamond & Graphite

Pure carbon is a semiconductor with negative temp coefficient of resistivity

brushes for electrical m/c
Non wire resistor

application

Lead (Pb) - High anti corrosion properties because of this properties it is used for laying of under ground and under water cable for power and communication line.

Platinum → Used for contact fabrication in low Power rating contactors.

(125)

Ni :- Used for making electrode.

INSULATING MATERIALS

Ceramics :-

properties → ① These material are hard, strong, dense & brittle.

② high temp. stability.

③ Generally inorganic material (absent of C so it is called inorganic) Except Sic

④ Generally Crystalline. (Except amorphous Glass).

⑤ These material are non metallic Oxide, Nitrides and Carbides.

Ex - Garnets, BaTiO_3 , ferrites, TiO_2 (Rutile) (Ti dioxide), Quartz, ZnS , MgO , Sic, Cds etc.

Types of Ceramics →

- (1) Porcelain ($\epsilon_r < 12$),
- (2) Steatite ($\epsilon_r < 12$)
- (3) Alumina ($\epsilon_r < 12$)
- (4) Titanate ($\epsilon_r > 12$)

Porcelain — Used in low and high Voltage applications.
Used in insulation of transmission & distribution of P.S. (126)

Steatite — Used in high freq application.

Alumina — high temp. application,
Used in C.B and resistance Cores.

Titanate — Used in capacitor application, due to high dielectric constant.

Another classification of Ceramic →

$\epsilon_r < 12$ — used as insulator.

Ex- Alumina, Porcelain, steatite.

$\epsilon_r > 12$ — Used in Capacitor application because of high dielectric constant.

Ex- Titanate & Rutile.

2) Transformer Oil → Transformer cores are dipped in mineral oil.

Known as T/F Oil

It act as an insulator.

o → It act as an cooling medium.

c → Parameter determining the properties the p/T/F oil

Viscosity — (It should be low)

(122)

Specific Gravity...

Pour point —

~~***~~ Flash point —

b
→ break down Voltage of T/F oil decrease with Contamination Ex- moisture

→ To absorb moisture, absorbants added are
• Silica gel and Allumina.

(3) Askorels →

→ They are fire resistance insulating material

→ Two types of Askorels

├→ Chlorinated benzene
└→ " biphenyl.

→ Now a days they are not used in T/F and Capacitor because on decomposition they produce Toxic & poisonous Gases.

→ ESM (Elemental S/c materials)

→ CSM (Compounded S/c materials).

→ As Conductivity & band gap are limited for ESM hence their usefulness is limited. So Group-3

~~III-IV~~

→ So, Grp. III-V, II-VI, IV-IV, IV-VI, S/c is used to provide better properties.

ESM — Eg- Ge, Si, C, B, Al, Ga, P, As, Sb, Bi etc.

As → It is pentavalent S/c material

Used as donor N-type S/c material.

When it is alloyed with Gallium, then it is used in fabrication of LED.

Se — (Selenium) → It is used in photo voltaic Cell.

CSM →

III-V S/c material — They provide wider range of band gap and extended op. range of device.

→ Structure is Zinc blende & diamond cubic.

Ex- GaAs, AlP etc

- GaAs :-
- (1) Large band gap material
 - (2) Large electron mobility which helps in high speed switching.
 - (3) direct band gap material.
 - (4) It is 10 times costlier than Si
 - (5) It is 2.5 times faster than Si based device

(129)

→ In GaAs crystal, Ga substitute corner and face atoms where as As takes place of 4 inside atoms.

Application —

- (i) LED
- (ii) LASER
- (iii) Satellite amplifier.

(B)

Group - II - VI S/c material →

Ex - Cds, CdSe, CdTe, ZnS, ZnSe etc

Used in photo
Conductor

- Band Gap is larger than Grp - III - V S/c
- Cds, CdSe, CdTe can be used as photo conductors.

1) IV-IV \rightarrow

Ex - SiC

(136)

It Bandgap is 3 eV

X-SiC can be used for high Temp. devices.

Drawback - Expensive & not easy to manufacture

2) IV-VI S/c -

Ex - PbS, PbSe, PbTe

In these S/c excess Pb gives rise to N-type S/c and less Pb gives rise to P-type S/c.

3) Amorphous S/c material \rightarrow

Structure is similar to super cooled liquid

Atom upto first nearest neighbours are arranged periodically,

but the atoms which are away from the first nearest neighbour are found to be arranged randomly.

There are 3 type of Amor. materials.

\rightarrow Elemental amorphous S/c
Ge, Si, Se, Te

\rightarrow Covalent " S/c
Ge, Te

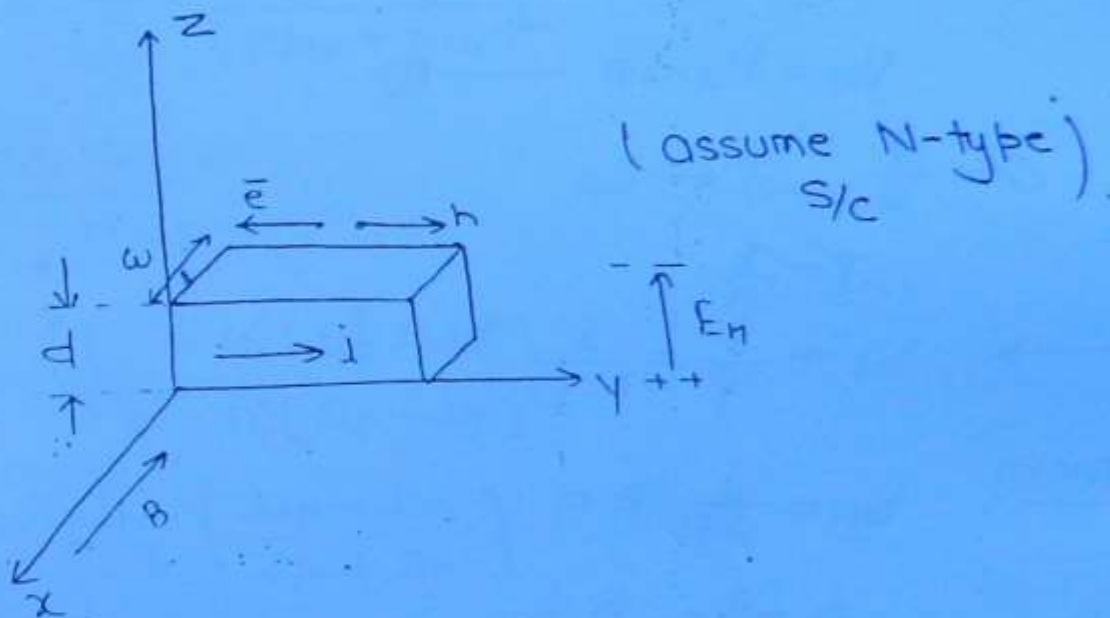
\rightarrow Ionic " "
 Al_2O_3 , V_2O_5

Hall effect

(131)

When a current carrying specimen is placed in a transverse mag. field then an electric field induced \perp to current & mag. field.

Let us consider a current carrying specimen is placed in mag. field (\vec{B})



Let us consider an N-type S/c. Suppose an electric current flow in positive y direction and mag. field is applied (-x) direction. A force called Lorentz force is excited on \bar{e} as well as holes in (+ve) z direction.

The minorities hole will recombine with majority electron. The movement of \bar{e} in the upwards direction disturbs the local neutrality of the S/c.

The application of Lorentz force will result in the formation of a negative layer on the upper side of specimen & positive layer due to immobile ion on the bottom side of specimen at equilibrium. —

$$e E_H = e v_d B$$

(132)

$$\frac{v_H}{d} = v_d \cdot B$$

$$v_H = v_d \cdot d \cdot B \quad \text{--- ①}$$

$$J = \frac{A}{A} \quad J = \sigma E_H$$

$$J = \frac{j}{A}$$

$$\rightarrow v_d = \frac{j}{P} = \frac{j}{A \cdot P}$$

from ①

$$v_H = \frac{j}{A P} \cdot B \cdot d$$

$$= \frac{j}{(dw) P} \cdot B \cdot d$$

$$v_H = \frac{B j}{P w}$$

$$v_H = R_H \left(\frac{B j}{w} \right)$$

Where R_H - Hall coefficient

$$= \begin{cases} \frac{1}{P} & \text{When } \bar{e} \text{ is moving drift Veloc.} \\ \frac{3\pi}{8P} & \text{When } \bar{e} \text{ motion is random.} \end{cases}$$

$$R_H = \begin{cases} -ve & , n\text{-type} \\ +ve & , p\text{-type} \end{cases}$$

$$V_H = \begin{cases} -ve & n\text{ type} \\ +ve & p\text{ type} \end{cases} \quad (133)$$

for comparable \bar{e} & hole concentration.

$$R_H = \frac{1}{P} \cdot \frac{P\mu_p^2 - n\mu_n^2}{(P\mu_p + n\mu_n)^2}$$

for intrinsic s/c -

$$n = p = n_i$$

$$R_H = \frac{1}{n_i q} \cdot \frac{n_i [\mu_p^2 - \mu_n^2]}{n_i^2 [\mu_p + \mu_n]^2}$$

$$R_H = \frac{1}{n_i^2 q} \left(\frac{\mu_p - \mu_n}{\mu_p + \mu_n} \right)$$

Since $\mu_n > \mu_p$

$R_H = -ve$ for intrinsic s/c

$$\underline{R_H} =$$

Si	$\rightarrow -10^9$
Ge	$\rightarrow -10^6$

Application -

- To determine the type of semiconductor (134)
 - To determine carrier concentration
 - To Calculate mobility of carries
 - It is used in hall effect multipliers
 - Can be used as a mag. field meter.
-

Electret → dielectric materials having permanent electrical dipole moment. are known as electret.

Gauss Meter — It is used to measure ^{Electric (mag.)} flux density. It is based on hall effect material.